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# Quantifying the Economic and Environmental Tradeoffs of Electricity Mixes in Texas, Including Energy Efficiency Potential Using the Rosenfeld Effect as a Basis for Evaluation

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# Quantifying the Economic and Environmental Tradeoffs of Electricity Mixes, Including Energy Efficiency Potential Using the Rosenfeld Effect as a Basis for Evaluation

**by**

**Melissa Christenberry Lott, B.S.E.**

**Thesis**

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# Dedication

I would like to dedicate this thesis to my family. These amazing people have not only given me their love and unfailing support, but have also served as some of my most influential teachers and inspirational role models.

I am grateful to have each of you in my life.

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To my family, thank you for being sources of constant support and love. I am a better person for knowing each of you.

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## Abstract

**Quantifying the Economic and Environmental Tradeoffs of Electricity Mixes in Texas, Including Energy Efficiency Potential Using the Rosenfeld Effect as a Basis for Evaluation**

by

Melissa Christenberry Lott, MSE, MPAff

The University of Texas at Austin, 2010

Supervisor: Michael E. Webber

Electricity is a complex and interesting topic for research and investigation. From a systems level, electricity includes many steps from its generation (power plants) to transmission and distribution to delivery and final use. Within each of these steps are a set of tradeoffs that are region-specific, depending heavily on the types of generation technologies and input fuels used to generate the electricity. These tradeoffs are complex and often not positively correlated to one another, producing a web of information that makes conclusions regarding the net benefit of changes to the electricity generation mix unobvious and difficult to determine using general rules of thumb. As individuals look to change the mix of technologies and fuels used to generate electricity for environmental or economic reasons, this complex web results in a lack of clarity and understanding of the consequences of particular choices.

Quantitative tools could provide individuals with clear information and improved understanding of the tradeoffs associated with changes to the electricity mix. Unfortunately, prior to this research, no such tools existed that provided a clear, rigorous, and unbiased quantitative comparison of the region-specific environmental and economic tradeoffs associated with changes to the electricity mix. This research filled this gap by developing a methodology for calculating the environmental and economic impacts of changes to the electricity generation mix for individual regions. This methodology was applied specifically to Texas to develop the Texas Interactive Power Simulator (TIPS), an interactive online tool accessible via the internet. This tool is currently used for direct instruction at The University of Texas at Austin for undergraduate courses. Preliminary data were collected to determine the usefulness of this tool as a classroom aid. These data revealed that a majority of students enjoy using the TIPS tool, felt that they learned about the tradeoffs of electricity generation methods by using TIPS, and wish that there were more learning tools like TIPS available to them.

This research also investigated the potential to use energy efficiency to satisfy a portion of the electricity demand that would otherwise be supplied using a generation technology. The methodology and series of decision criteria that were developed with this investigation were used to determine the amount of generation that could reasonably be satisfied with energy efficiency technologies and supportive policies for a particular region of interest, in this case Texas. This methodology was established using the Rosenfeld Effect as a basis for evaluating the energy efficiency potential in a specific region, providing a more realistic maximum energy efficiency value than using theoretical maximum gains based on current best available technology. It was then compared to efficiency potential estimates by the American Council for an Energy-Efficient Economy (ACEEE) and the Public Utility Commission of Texas (PUCT). In this research, I found that Texas is unlikely to realize more than an annual savings of 11% or about 1.5 megawatt-hours per capita compared to 2007 use levels based on nominal energy efficiency approaches. When this potential savings was applied to offset future demand increases in Texas, it was found that new generation capacity would still be needed over the next few decades to meet increasing total electricity demand.

I used the economic and environmental tradeoff analysis and energy efficiency limitations methodologies that I established in my research to calculate the economic and environmental tradeoffs of changes to the electricity mix resulting from several scenarios, including federal energy and climate legislation, nuclear renaissance, high wind power growth, and maximizing energy efficiency. The outputs from these scenarios yielded the following observations:

1. Energy efficiency is unlikely to replace more than 11% of total per capita electricity demand in Texas. This level of energy efficiency might reduce total demand in the state, but population growth and its corresponding impacts on state electricity use might outpace the savings from energy efficiency in the long-term. This population growth could result in an overall increase in total annual state electricity use, despite energy efficiency gains.

2. While nuclear power might be environmentally advantageous from the standpoint of total emission of greenhouse gases compared to fossil fuel-fired power plants, it has very high up-front capital costs and is very water-intensive.

3. A federal combined energy efficiency and renewable portfolio standard might require states to install new renewable power generation capacity. In some states, including Texas, the amount of required new generation capacity may be small because of existing state initiatives encouraging renewable generation capacity to be installed in the state and the potential to offset some generation requirements using energy efficiency.

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## Nomenclature

| | |
|---|---|
| $C_{total}$ | annual cost (O&M, fuel, environmental impacts cost) for total generation from source |
| CC | capacity costs ($/MW) |
| Externalities | annual cost of environmental externalities ($/MWh) |
| Fuel | annual cost of fuel |
| $i$ | market discount rate (%) |
| IC | initial installed cost ($) |
| IDC | interest during construction ($) |
| $N_{constr}$ | number of years the power plant is under construction (years) |
| $N_{years}$ | economic life of power plant (years) |
| O&M | cost of power plant operation and maintenance ($/MWh) |
| $r$ | construction loan interest rate (%) |

## Acronyms and Abbreviations

$/MWh – U.S. dollar per megawatt-hour

AWEA – American Wind Energy Association

CDD - cooling-degree day

$CO_2$ – carbon dioxide

CREZ – competitive renewable energy zone

CSP – concentrating solar power

EE – Energy Efficiency

EERE – office of Energy Efficiency and Renewable Energy

EIA – Energy Information Administration

EPA – United States Environmental Protection Agency

EPRI – Electric Power Research Institute

ERCOT – Electric Reliability Council of Texas

gal - gallon

$H_20$ - water

HDD - heating-degree days

HHS – average household size

IEA – International Energy Agency

IGCC – Integrated Gasification Combined Cycle Power Plant

kW - kilowatt

kWh – kilowatt-hour

lb – pound

LCOE – levelized cost of electricity

MW – megawatt

MWh – megawatt-hour

NG – natural gas

$NO_x$ – nitrogen oxides

NREL – National Renewable Energy Laboratory

PC – Pulverized Coal

pph – people per household

PTC – production tax credit

PUCT – Public Utilities Commission of Texas

PV – present value

PSP – photovoltaic solar power

RPS – renewable portfolio standard

SECO – Texas State Energy Conservation Office

$SO_2$ – sulfur dioxide

TIPS – Texas Interactive Power Simulator

TX – Texas

UT – The University of Texas at Austin

W - watt

# Chapter 1: Introduction

## 1.1. MOTIVATIONS

Concerns surrounding the sustainability of the United States' electricity sector include topics not only focused on resource availability and depletion, but also broader environmental impacts and economic suitability. As interest increases regarding the long-term effects of greenhouse gas emissions into the air, the availability of water, and the usability of land for agricultural and other purposes, it becomes prudent for us to dedicate resources to developing a sustainable energy systems framework. Quantitative tradeoffs analysis could play a central role in evaluating the tradeoffs of system options. This, in turn, could help guide the decision-making process by providing unbiased quantitative information . However, to ensure the usefulness of these quantitative tools they could also include educational components, geographic specificity, practical limitations for technology use, and the inclusion of energy efficiency technologies to meet electricity demand.

There is an existing need for readily accessible quantitative feedback on the economic and environmental tradeoffs of electricity generation technologies, provided in a manner that makes it useful to not only researchers and analysts, but also to individuals and groups with little experience in electricity markets or with generation technologies. Thus, a feedback tool that is not only technically rigorous, while also presented in a fashion that is easily comprehended by broad audiences that might not have previous experience with energy technology, would be useful. This need for appeal to broad audiences inherently includes a need for educational components to help users develop a basic understanding of electricity generation technologies and systems.

Further, the economic and, in particular, the environmental tradeoffs of electricity systems depend greatly on geographic location. For instance, while Texas generates nearly half (49%) of its electricity using natural gas, the state of Washington uses natural gas for only 9% of its total generation and instead depends on hydroelectric power for the majority (nearly 72%) of electricity generation. Conversely, Indiana relies on fossil fuels (coal and natural gas) for 85% of the state's electricity. (1) Changes in the generation technology profile, for example to meet a Renewable Portfolio Standard (RPS) or to integrate less water-intensive technologies such as wind or solar power, would have different implications for each of these three states. Therefore, feedback tools might be more useful and accurate if tailored to the region of interest.

Tradeoff analysis tools could also include reasonable capacity limits (percent of total generation) and capacity factors for each technology, as it pertains to grid reliability and technical limitations due to fuel availability. They could also determine the amount of capacity required to meet changing electricity demand due to growing populations or per capita electricity requirements. Fuel availability is particularly critical for renewable technologies that utilize intermittent fuel sources such as wind and sun. Energy efficiency could also be included, as it can satisfy a portion of the electricity demand but, unlike conservation, has associated economic costs.

### 1.2 EXISTING ANALYSIS TOOLS

There are several publicly available tools that compare electricity generation technologies. However, while they excel in one or two areas – for example, they have a aesthetically pleasing presentation or quantitative outputs - they are generally limited in scope or transparency, for example very rarely including any type of regional specificity or displaying equations used in calculations. For example, many of the world's major oil

& gas companies have their own online tools available for consumer use via their corporate website. Each has an apparently differing goal. For instance, BP's online tools focus primarily on consumer's personal energy use and carbon footprint (2). Chevron's "Energy Generator" focuses on how to save energy through small changes in the user's lifestyle (3). Both of these tools include interactive components for users, as well as quantitative outputs. However, reproducing the calculations used by these tools is difficult because the underlying equations and input data used are not readily available. Further, these tools do not allow the user to specify a particular region (for example, state or town) for the analysis so that regional characteristics and differences (for example, generation mix or average per capita electricity consumption) can be included in the analysis.

Research institutions have also designed energy generation analysis tools that are available online. One such example is HOMER, a micropower optimization model developed by the National Renewable Energy Laboratory that is designed to optimize off-grid and grid-connected renewable systems through multivariable system analysis (4). Its design is thorough, offering many types of renewable technologies for use in the design of one's system. The equations and input data used are also available to the user, with relative ease compared to the industry tools discussed previously. However, HOMER's focus on small-scale off-grid renewable systems makes it inapplicable for people to learn about grid-scale designs and grid-reliant systems, which most of our residential and commercial systems are.

The Renewable Energy Costs and Benefits for Society (RECaBS) tool allows for more technologies than HOMER, including coal with carbon capture, coal combined heat and power systems, and waste incineration (5). However, its design does not incorporate other technologies that are prevalent today including natural gas and nuclear power generation technologies. Additionally, it is difficult to access the equations and input data used in order to reproduce the calculations to ensure validity of the tool.

In the aforementioned tools, the potential to offset some electricity generation requirements via energy efficiency technologies and programs is not included in their tool designs. Energy efficiency potential is generally presented separately from tools that analyze the tradeoffs of electricity generation technologies. For example, the United States Environmental Protection agency (EPA) provides a tool for calculating the energy savings associated with replacing the lightbulbs in your home with types of energy efficient light bulbs in their online Life Cycle Cost Estimate for 1 ENERGY STAR Qualified Compact Fluorescent Lamp(s) tool.(6) This tool provides the user with the energy, cost, and air pollution savings for a year of compact fluorescent light bulb use. However, it does not give the user a comprehensive picture of the energy savings potential of all energy efficient technologies and practices available to a homeowner. It also does not allow the user to easily extend these savings to a region by increasing the number of households without the user conducting outside research regarding, in this case, the number of households in a region and the average number of light bulbs used in these households. This tool's technology-specific approach and limited reach make it unacceptable for the capabilities needed for a comprehensive tradeoff tool.

### 1.3 COMPREHENSIVE ANALYSIS TOOL

I sought to develop a tool that is transparent and can flexibly incorporate a large number of generation technologies. My particular applications further required a tool that was region-specific. Due to the shortcomings of existing tools in terms of their ability to satisfy my analysis needs, I developed a methodology for calculating the economic and environmental tradeoffs of electricity generation mixes - including energy efficiency potential - and applied this energy efficiency potential to the state of Texas, creating the Texas Interactive Power Simulator (TIPS).

In the following Chapters included in this thesis, I will first provide details on the Texas electricity mix and regulatory climate to give the reader a sense of why this state was used as an illustration of the applications of the tradeoff analysis and energy efficiency methodologies. I will then discuss the development of these two methodologies, using the state of Texas as an example region. Included in this discussion is information about the teaching and learning tool that was developed using the tradeoff analysis methodology in order to provide access to the information provided by this methodology's outputs. This discussion includes data pertaining to how students have responded to its use in the classroom at The University of Texas at Austin. The discussion will then cover four scenarios (carbon price, nuclear renaissance, high wind growth, and maximizing energy efficiency) analyzed to illustrate the usefulness of these methodologies.

# Chapter 2: Background

## 2.1 Overview

This chapter provides background information on the state of Texas to provide context for the reader when looking at subsequent sections that deal with applying tradeoff analysis and energy efficiency potential to the state. Noted here is the fact that Texas was not chosen as the region of interest for this analysis simply because it is the home of The University of Texas at Austin, though this was certainly advantageous when using the Texas Interactive Power Simulator in the classroom. Texas is a fascinating region to study when looking at electricity generation because its power grid is distinct from the rest of the nation, it has different regulatory design (including a mix of competitive markets, regulated utilities, large electric cooperatives, and statewide requirements for renewable energy) and is has witnessed significant addition of renewable electricity generation capacity (predominately wind) over the past decade.

## 2.2 Texas's Electricity Sector – Present Day

Texas generates and consumes more electricity than any other state in the United States. In 2007, power plants in Texas generated more than 400 terawatt-hours of electricity, with 49% from natural gas as a fuel source as shown in Figure 1, below. Texas emits more air emissions of carbon dioxide and nitrogen oxides from the generation of electricity than any other state, emitting more than 250 million metric tons and 260 thousand metric tons respectively during 2007. At the same time, Texas emissions rates per quantity of electricity generated (e.g. lbs $CO_2$/kWh) are below the average in the United States because of the extensive use of natural gas. (7)

In Texas, the current generation mix consists of 95% non-renewable generation and 5% renewable generation as shown below in Figure 1.

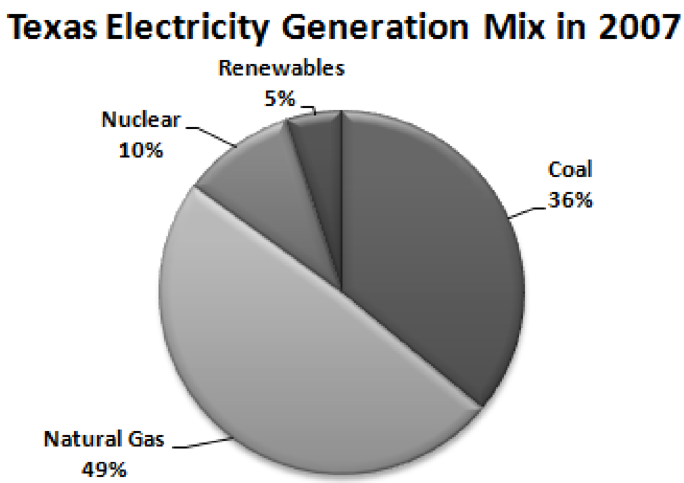



Figure 1: The Texas electricity generation mix in 2007 included 5% of total generation coming from renewables (8)

In addition to a fuel mix that is different than the national average, Texas also has a distinct grid. In particular, there are three main interconnections in the continental United States: East, West and Texas. These interconnections are shown in Figure 2, below(9). The majority of the electricity used in the state is transmitted over the Texas power grid, as managed by the Electric Reliability Council of Texas (ERCOT).

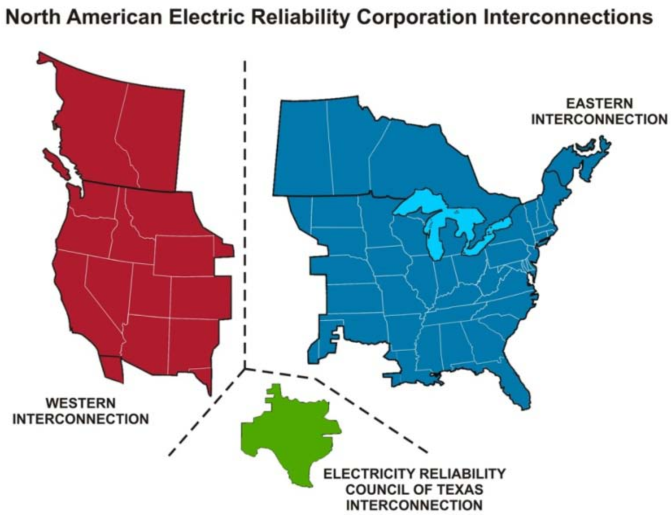



Figure 2: There are three main interconnections in the continental United States (9)

The state of Texas was the second state in the United States to establish a state renewable portfolio standard (RPS), which requires a certain portion of the state's generation capacity to use renewable fuel sources (for example, wind). (10) Under the 1999 Texas State Senate Bill 7, the state mandated that 2,000 MW of renewable energy capacity be installed by 2009. Also included in this bill were energy efficiency targets for electricity distribution companies.(11) (12) Since 1999, due largely to the rapidly growing wind power industry in Texas, the renewable portfolio standard has been amended.

Most recently in August of 2005, Texas State Senate Bill 20 passed, requiring 5,000 MW of newly installed renewable capacity by 2015. This bill also includes a target of installing 500 MW of non-wind renewable capacity within the 5,000 MW. Further, this bill established a long-term goal of 10,000 MW of new installed renewable energy capacity by 2025, with a recommendation that 500 MW of this capacity be satisfied with non-wind renewable capacity. (13) As of early 2009, Texas had installed 7,907 MW of wind power capacity, primarily in the western half of the state.(14)

The increase in installed wind power was - and continues to be - complemented by the large amount of natural gas capacity in Texas, which makes the state more agile in responding to shifts in resource availability for intermittent resources like wind. Without this natural gas capacity, it could be more difficult for Texas to rely on a high level of wind generation capacity. Natural gas, with its faster ramp rates compared to other technologies, provides back-up in case of drops in wind as was seen on February 26, 2008. On this Tuesday evening, 1,400 MW of wind power capacity that had been actively generating electricity ceased generating due to a drop in wind. This drop resulted in the curtailment of 1,100 MW of demand from interruptible customers when natural-gas fueled ancillary service providers failed to deliver contracted power(15).

# Chapter 3: A Methodology for Establishing Energy Efficiency Potential, Using the Rosenfeld Effect as a Basis of Evaluation

## 3.1 OVERVIEW

Energy efficiency might be able to provide an economically advantageous alternative to new generation capacity and is therefore a potentially important addition to any tradeoff analysis tool. At a cost of $350 per kilowatt avoided versus $900 or more per kilowatt of new generation capacity, energy efficiency programs and technologies might allow consumers to realize energy savings without making behavioral changes. (16)(17) Also, these energy efficiency savings could be seen as environmentally beneficial, if they offset electricity that would be generated at a power plant that negatively affects the environment. For instance, each kilowatt-hour (kWh) that is not generated at a coal power plant because of a more energy efficient refrigerator will eliminate emissions of carbon dioxide and other greenhouse gases.

Energy efficiency can be used to satisfy some of the anticipated electricity demand by end users, by decreasing the amount of electricity required for these customers to complete desired tasks. Efficiency differs from conservation in that it does not require the end user to cease activities or change behaviors to reduce their energy use, but rather allows them to complete their tasks using less energy. To illustrate the difference, efficiency is achieved through the incorporation of better technology (e.g. a better air conditioner system), whereas conservation is achieved by setting the thermostat for the air conditioner to a higher temperature.(18)(19) Because consumers are not "doing less," it is not possible for energy efficiency to take total electricity demand to zero. Therefore, practical limits on the savings possible using energy efficiency technologies could be determined. The following sections outline the methodology established by this research to determine the total energy efficiency potential for a designated area.

## 3.2 THE ROSENFELD EFFECT

Choices made by the state of California in the 1960s and 1970s show how requirements and incentives for structures and electricity customers to be more energy efficient can dramatically impact the per capita electricity use for large regions. California, has experienced near-constant level of per capita electricity consumption in California since 1973; (20) this phenomenon is called the "Rosenfeld Effect" in honor of Dr. Arthur H. Rosenfeld (often referred to as the "godfather of energy efficiency"). California's experience with the Rosenfeld Effect demonstrates the ability of a large region in the United States to stabilize its per capita electricity use, effectively offsetting some of its demand with efficiency instead of generation. In 2010, Dr. Rosenfeld was honored by having a unit of measurement named for him. One Rosenfeld represents a savings of three billion kilowatt-hours (kWh) per year, or the amount of power generated by one 500 MW coal-fired power plant.(21)

As shown below in Figure 3, per capita electricity use in California only increased by 8% from 1973 to 2007. During the same timeframe, annual per capita electricity consumption (across all sectors) in Texas increased by 41% from 10.2 to 14.4 megawatt-hours with a simultaneous state population increase. (22) (23) (24) These factors yielded a statewide annual electricity sales increase from 123 terawatt-hours (TWh) in 1973 to 344 TWh in 2007. The United States per capita electricity use increased by 54% over this 34 year period.

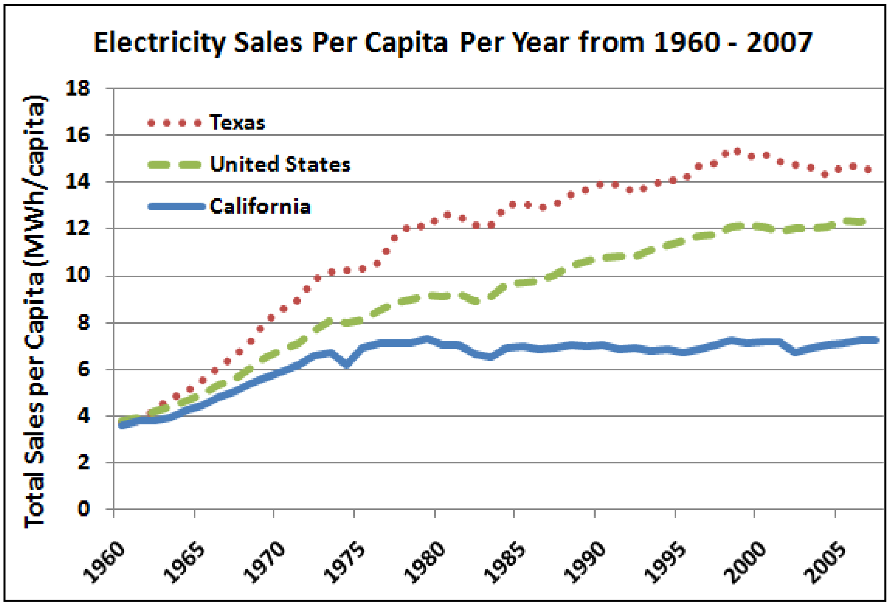



Figure 3: Electricity sales per capita per year including all sectors for Texas, California, and the U.S. from 1960-2007 show California's Rosenfeld Effect (22-24)

The Rosenfeld Effect has been studied to discover what factors enabled California to achieve its distinctive consumption profile. These findings have been used in this research to see if Rosenfeld Effect could be achieved in other states, and to what extent it could be replicated. (20)

This research project first evaluated the potential causes of the Rosenfeld Effect, primarily using previous studies conducted at Stanford University. It then seeks to establish a methodology for determining limits for energy efficiency savings for particular regions. (25) This methodology was then applied to the state of Texas and the determined range of potential savings was compared to published potential savings values published by the Public Utility Commission of Texas (PUCT) and the American Council for an Energy-Efficient Economy regarding potential savings from energy efficiency in Texas. (26) (27) This analysis did not consider capacity avoidance savings from demand response programs, but only considered generation (kWh) savings from increased efficiency in electricity use. Also, the transportation sector was not included in this analysis because this sector does not currently rely on electricity as a fuel in most cases.

### 3.3 The Rosenfeld Effect in California - Contributing Factors

According to an analysis conducted by Stanford University in 2008, eleven distinct impact categories have led to a significant portion of the per capita electricity use savings seen in California relative to the United States. (25) This analysis identified these savings by category and sector (residential, industrial, and commercial). These eleven impact categories are listed below in Table 1, along with the percent of total savings compared to average U.S. per capita electricity use. Due to availability of data at the time of the Stanford analysis, the electricity "savings" in each sector was analyzed for different years, as indicated in the table below. The categories identified by the Stanford analysis do not account for all electricity saved in these sectors, though they do quantify "savings" in perhaps the most interesting category, that of state energy efficiency policy.

Throughout the Stanford analysis, the authors used the term "savings" to indicate the per capita kilowatt-hour (kWh) difference between the U.S. average and California's electricity use attributed to that category. This term implies that some type of action on the state of California's part directly caused reduction in electricity use. However, as will be shown in the following sections of this thesis, most of the categories described are not actually savings, but are more accurately described as reductions in electricity needs due to geographic factors. For instance, a large portion of the "savings" identified by the Stanford analysis are the result of the relatively mild climate that California experiences, in particular during the summer season. This mild climate is advantageous in terms of reducing the cooling load during the summer compared to other states. But, it is hardly true that Californians made choices that resulted in this advantageous (from an electricity use perspective) climate. Rather, any reduction in electricity use is due to the location and its existing climate and geographic characteristics. This misuse of the term “savings” is potentially a major pitfall in the Stanford analysis, from the perspective of this research project. While the term “savings” will be used throughout this thesis, the term will be used with quotation marks to indicate the nebulous and problematic use of this term.

In Table 1, electricity “savings” was calculated as a percent of total U.S. average per capita electricity use for each sector. To calculate this value, the “annual per capita savings (kWh)” value is divided by the U.S. average per capita electricity use for the indicated year. The Stanford analysis also evaluated the electricity “savings” impacts of household income, householder age, and housing unit age. These impacts were found to be statistically insignificant and therefore are not listed in Table 1. (25)

Table 1: Electricity "savings" in California compared to U.S. average per capita electricity use by sector (25)

| | Savings (%) | Annual per capita savings (ACPS) in kWh |
|---|---|---|
| **Residential (2001)** | | |
| Cooling load reduction (climate and appliance type) | 7.80 ± 1.30 | 332 |
| Heating load reduction (climate and fuel choices) | 8.00 ± 1.36 | 340 |
| Water Heating load reduction (fuel choices) | 5.60 ± 0.97 | 238 |
| Household size effect | 11.0 ± 4.40 | 382 |
| Urban rural distribution (Urbanization) | 10.4 ± 1.04 | 321 |
| Possible Policy Share | 12.8 | 545 |
| **Industrial (2002)** | | |
| Industry Type and size differences | 38.00 ± 3.60 | 1,321 |
| On-site electricity generation differences | 7.40 ± NE | 257 |
| Possible Policy Share | 14.5 | 504 |
| **Commercial (2003)** | | |
| Reduction due to lower floor space intensity | 27 ± NE | 1,132 |
| Possible Policy Share | 5.7 | 236 |
| **TOTAL** | **--** | **5,608** |

### 3.4 Impact of Policy on Electricity Savings

The Stanford analysis determined that only a small portion of the electricity "savings" in California over the evaluation period were likely due to policy mechanisms such as increased emphasis on efficiency in building codes, appliance standards, and funding of energy efficiency programs. These policies required increased efficiency in new building construction and appliances while increasing energy use awareness of California electricity consumers. (25) The remainder was due to other trends in the state that corresponded with energy efficiency policy implementation. These trends ncluded changes in fuel choices for residential heating, increasing household sizes and levels of urbanization, as well as shifts in the types and sizes of industrial facilities operating in California. The extent to which these savings could and are likely to be realized in other states varies by sector according to the analysis of trends and future projections for electricity demand by sector. They are categorically addressed in the next three sections of this thesis for each sector (residential, industrial, and commercial).

### 3.5 RESIDENTIAL SECTOR

From 1970 to 2007, United States residential sector annual per capital electricity use increased from approximately 1 MWh to over 4.5 MWh, as shown below in Figure 4. At the same time, California has leveled its annual per capita electricity use at 2.5 MWh and Texas has seen its use soar to almost 5.5 MWh, peaking in 1996 at an annual per capita consumption of 5.6 MWh. Over the past decade Texas has perhaps achieved its own Rosenfeld Effect in the residential sector as shown by the flattening per capita electricity sales shown in Figure 4 (above) since 1996.

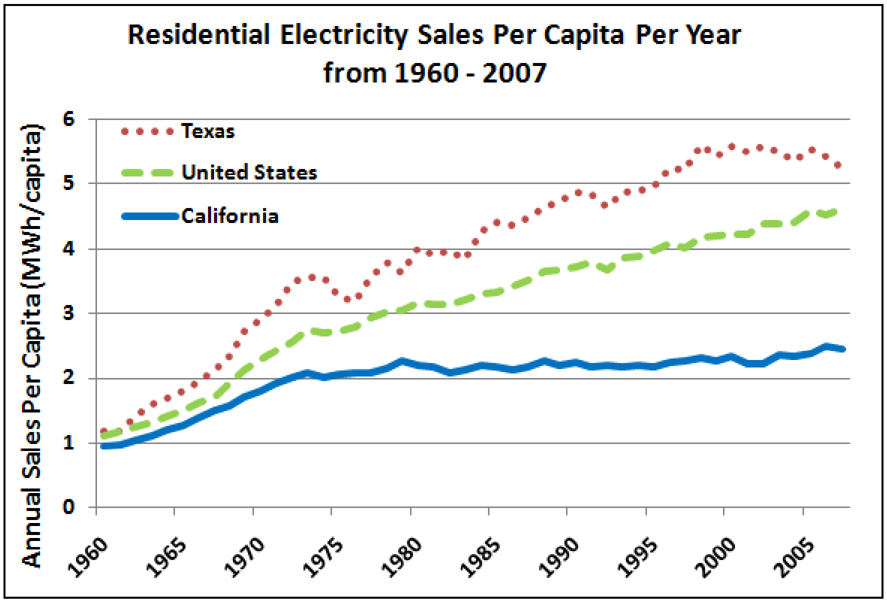



Figure 4: Residential electricity sales per capita per year from 1960 – 2007 in Texas, California, and the U.S. show a stabilization in Texas's net sales per year since 1996 (22-24)

The Stanford University analysis of the Rosenfeld Effect identified six electricity "savings" categories that contributed to the effects seen in California. They are listed below in Table 2. In this table, electricity "savings" was calculated as a percent of total U.S. average per capita electricity use for each sector. To calculate this value, the "annual per capita savings (kWh)" value is divided by the U.S. average per capita electricity use for the indicated year.

Table 2: Electricity “savings” in California compared to U.S. average per capita electricity use for the residential sector (25)

| | Savings (%) | Annual per capita savings (ACPS) in kWh |
|---|---|---|
| **Residential (2001)** | | |
| Cooling load reduction (climate and appliance type) | 7.80 ± 1.30 | 332 |
| Heating load reduction (climate and fuel choices) | 8.00 ± 1.36 | 340 |
| Water Heating load reduction (fuel choices) | 5.60 ± 0.97 | 238 |
| Household size effect | 11.0 ± 4.40 | 382 |
| Urban rural distribution (Urbanization) | 10.4 ± 1.04 | 321 |
| Possible Policy Share | 12.8 | 545 |
| **TOTAL** | **--** | **2,158** |

Two of these categories - heating and cooling load reductions - show that potential role of climate in determining the amount of energy efficiency that could be realized in a region. The potential for the local climate to impact the amount of energy efficiency “savings” indicates the potential for a lack of applicability of this category to other states. For example, New York’s cold winters and relatively harsh winter climate compared to California might prevent it from realizing the same energy efficiency gains as California from heating load reduction. Other categories, for example household size effect and urbanization, allude to a potential inability for more rural (lower population density) states to recognize these energy efficiency gains.

The following sections discuss my analysis of five of the six categories identified by Stanford University’s work in order to establish methodologies for determining when and to what extent these potential savings might be recognized in other states. The sixth category, possible policy share, was assumed to be applicable for the residential sector, in general. This assumption was made due to the broad arguments used by the Stanford University researchers to establish this savings category, which did not address the feasibility of passing additional legislation in the current political climate. For this analysis, I assumed that policy in support of energy efficiency could be passed in the state under discussion.

### 3.5.1 HEATING AND COOLING LOAD

The Stanford analysis of the Rosenfeld Effect identified reductions in electric heating and cooling loads compared to the U.S. average load through the use of more efficient HVAC appliances and by changes in fuel choices. Noted here is that any impact of “savings” realized through changes to building envelopes is included under the “possible policy share” category in this analysis. This classification might not be appropriate for this “savings”, as changes to the building envelope can have large direct impacts on heating and cooling loads and could be separated out into a seperate category. However, this discussion follows the Stanford classification system.

With respect to electricity “savings” due to improved heating and cooling technology, many areas in the United States are already offering rebates on energy efficient HVAC equipment in order to recognize these “savings”. However, it should be recognized that there could be negative economic and environmental impact ramifications associated with switching electric heating and cooling equipment to non-electric fuels. Conversely, there could be net benefits in terms of energy use, environmental impact, or economic cost if a household switched to non-electric fuels such as natural gas.

The Stanford analysis calculated California’s electricity “savings” based on the number of heating and cooling degree days in California versus the United States combined with the types of technology used in each. The second part of their analysis was not repeated at this time due to a lack of comparative data for the other 49 states in the United States for technology distributions. Instead, it was assumed that the technology profiles in terms of age and efficiency were approximately the same, which was verified to the extent it was possible using data from the Energy Information Administration's Residential Energy Consumption Survey (RECS). Therefore, I used the number of cooling and heating degree-days to establish a methodology for calculating the "savings" potential per state due to the climate.

According to the Annual Energy Review 2008 as released by the Energy Information Administration, the Pacific Region of the United States experienced 755 cooling degree-days in 2008 as shown below in Figure 5.

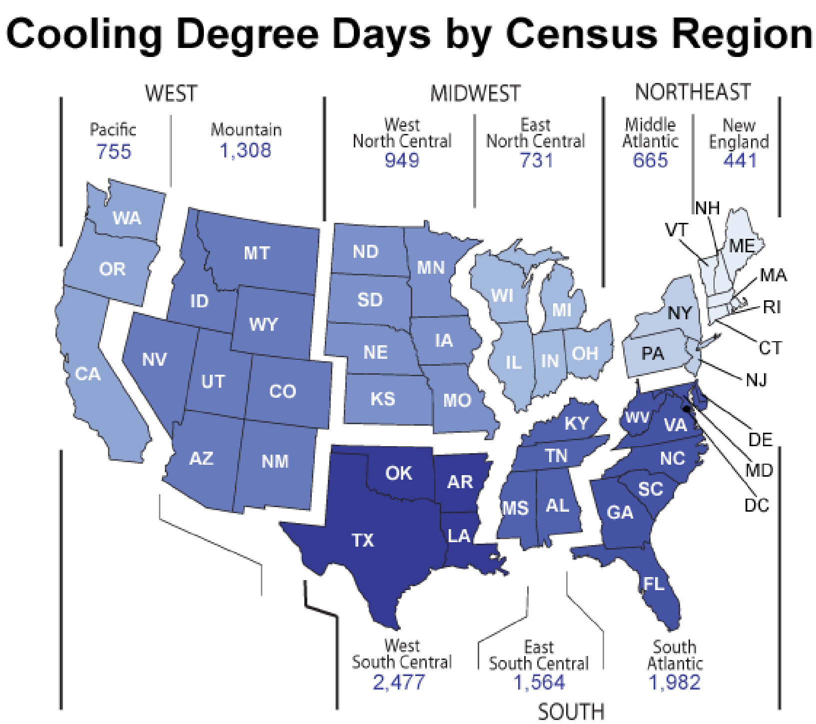



Figure 5: Cooling degree-days vary greatly throughout in U.S. (28)

The 30-year normal number of cooling degree-days in the United States of 1,242 per year likely makes it unwise to extend this “savings” category to most other regions of the United States without accounting for these differences. It likely does not make sense to say that a state with an above average level of cooling-degree days would not have a higher than average need for energy to cool its buildings. Because of this, I established the following methodology to determine the potential “savings” for each region based on cooling-degree days by region.

To calculate the potential “savings” in cooling load due to climate characteristics, I used the proportion of the difference in the number of cooling degree days where per capita electricity “savings” (ES) in kWh per cooling-degree day (CDD) below average was first calculated using the “savings” realized in California, as shown below in Equation 1.

$$ES_{cooling,climate,California} = \frac{332\ kW}{(1{,}242 - 755)\ CDD}$$

$$= 0.66\left[{}^{kW}\!\!\Big/_{CDD}\right]$$

Eq. 1

To establish the per capita annual energy efficiency “savings” potential (EESP) for any region (R), this factor is used along with Equation 2, shown below.

$$EESP_{cooling,R} = [1{,}242 - \ (CDD\ for\ region)] \times (0.66\,{}^{kW}\!\!\Big/_{CDD})$$

Eq. 2

The same methodology was applied to the second category of energy efficiency “savings” in Stanford’s analysis – electricity “savings” due to heating-degree days

(HDD). The United States experiences, on average 4,524 heating-degree days per year, as calculated using the data provided by the Energy Information Administration for Figure 6, below.

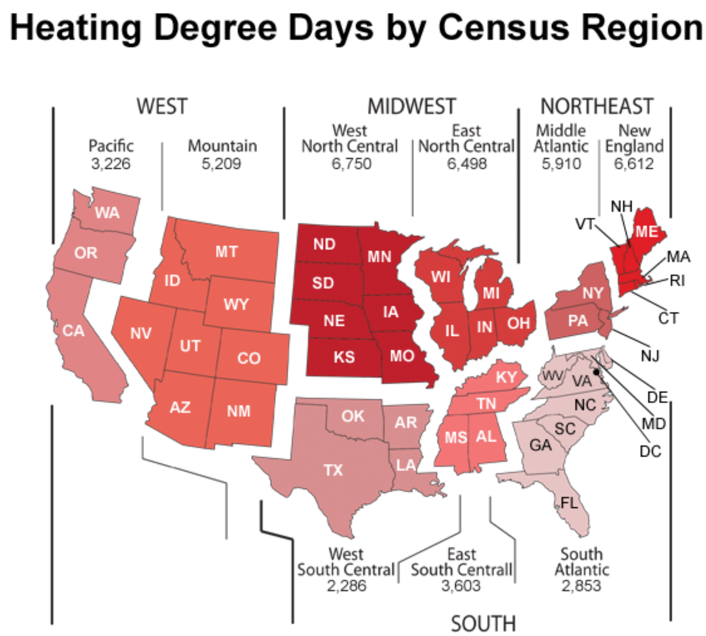



Figure 6: Heating degree-days vary greatly throughout the United States (28)

As with the cooling load calculations, the potential "savings" in heating load due to climate characteristics is calculated using the proportion of the difference in the number of heating degree where annual per capita electricity "savings" (ES) in kWh per heating-degree day below average was first calculated using the "savings" realized in California.

$$ES = \frac{340\ kWh}{(4{,}524 - 3{,}226) \times (HDD)} = 0.26 \left[{}^{kWh}/_{HDD}\right]$$

Eq. 3

To establish the energy efficiency "savings" potential (EESP) for any region (R), this factor is used along with equation 4, shown below.

$$EESP = (HDD\ for\ region) \times (0.26\ {}^{kWh}/_{HDD})$$

Eq. 4

Using the equations above, the annual per capita amount of electricity (kWh) that might be "saved" in a particular region due to climate differences compared to the United States average. This value is important not only in the potential "savings" it quantifies, but also because of its ability to quantify the impact of climate on electricity use. The outputted "savings" per cooling degree-day could be used to gain an idea of the additional amount of electricity that is used because a state has hotter summers or cooler winters compared with other states. In this particular case, it can be used as an indicator to gauge the possible limits to efficiency gains in heating and cooling loads due to a region's specific climate.

### 3.5.2 WATER HEATING

The third impact category identified in the Stanford analysis is electricity "savings" due to load reduction for water heating. (25) Noted in the analysis is that a portion of the residential sector water heating load reduction (238 kWh per capita) could be attributed to California state policies that make the construction of all-electric buildings difficult, leading to increased natural gas use for water heating purposes. Specific examples of such policy are found in the California Code of Regulations Title 24, also known as the California Building Standards Code.(29) However, as this impact could not be measured directly, it was classified under the residential water-heating category. (25)

Electricity "savings" might be recognized using new technologies or by converting residential electric water heating units to natural gas units. Key new technologies such as modern heat pump water heaters can reduce water heater operating costs by up to 62% compared to conventional electric water heaters. (30) The extent to which this "savings" from fuel switching could be applied depends on the percent of the total residential units in a region that could be converted to natural gas units. This value is determined by first establishing the percent of total households that have access to natural gas at their residence and then by evaluating state and local policies that might prevent or require natural gas use in residential homes.

In the absence of policies disallowing conversion of water heating units to natural gas units, it is still reasonable to assume that significant "savings" could be realized by switching existing units to more energy efficient units. Therefore, it is reasonable to conclude that other regions and states in the United States could recognize the total "savings" recognized in California in this category.

### 3.5.3 HOUSEHOLD SIZE

In the Stanford analysis, it was determined that 382 kWh of annual per capita electricity "savings" in California compared to the United States average could be attributed to increased household size. The Stanford analysis neglects any cultural, social, or other factors that might contribute to increased household sizes. It also neglects to include factors such as the average building square footage per household member, resulting in a nebulous conclusion that should not be immediately extended to other states when analyzing energy efficiency "savings" potential. However, as it was included in the Stanford analysis, it will remain a part of the methodology presented here at this time. As is discussed in further detail below, the average household size by state in the United

States do not include a very large range of values. Therefore, the potential “savings” in this category is limited.

California has an average household size (HHS) of 2.87 people, slightly higher than the U.S. average of 2.6 people per household (pph). This difference of 0.27 people per household is used to determine the electricity “savings” potential for any particular state. In order to calculate the electricity “savings” potential due to household size, the following equation is used:

$$ES_{HHS,California} = \frac{382\ kWh}{(2.87 - 2.6\ pp\ \ )} = 1{,}415\ kWh\ \ /pph$$

Eq. 5

In other words, very small increases in average household size, when extended to an entire state can lead to lower  per capita electricity use. Electricity “savings” (in kWh per person) for a general region (R) can be quantified using Equation 6, below.

$$ES_{HHS,R} = (HHS\ in\ region - 2.6) \times 1{,}415\ ({}^{kWh}/_{pph})$$

Eq. 6

This equation shows that the effect of household size on average per capita electricity sales is seemingly very large. Utah currently has the highest average household size of the 50 states with an average household size of 3.01 and the District of Columbia has the smallest average household size at 2.08 people per household. (31)

### 3.5.4 URBANIZATION

The previous analysis by Stanford University identified urbanization as a large contributor in terms of total energy efficiency “savings,” being responsible for approximately 10% of total annual per capital “savings” contributing to the Rosenfeld

Effect. In order to determine what portion of these "savings" can reasonably be extended to other states, it would be helpful to first establish the overall level of urban versus rural populations for each state. However, as indicated by the author's of the Stanford analysis, urban versus rural mappings by the U.S. Census Bureau do not readily allow for this reconstruction.

Therefore, when extending the "savings" (kWh) due to urbanization realized in California to other states, a very general conclusion was reached and incorporated into the methodology presented in this thesis. Simply put, if the level of rural to urban populations is the same or more than that seen in California, it is concluded that the "savings" due to urbanization can be extended to the state being analyzed. This urbanization level is as established by the U.S. Census Bureau for the year 2000. In this year, California had a recorded urban population topping 92% of the state population, leaving only 8% of the population living in rural areas. (32) If this was, for example, compared with Texas where the split is closer to 80% urban and 20% rural, it would be deemed unlikely that Texas could recognize the energy efficiency gains of a more heavily urban state. Therefore, this "savings" category potential for Texas is considered to be zero. Alternatively stated, because Texas has a relatively large percentage of its population living in rural areas compared to California, it is unlikely to be able to recognize the energy efficiency gains from having a more concentrated urban population.

### 3.6 Industrial Sector

Evaluating historic trends in per capita industrial sector electricity sales in the United States, California, and Texas reveals that each has maintained a relatively constant or declining level of annual sales on a per capita basis since the early 1980's as shown in Figure 7, below. However, similar to what was seen in the residential sector analysis, the

United States and Texas annual per capital sales (MWh/year) in the industrial sector greatly exceed that in California. The term "sales" as it is used in this thesis indicates the amount of generation that is sold to the end-use customer, as opposed to the gross amount of electricity generated at the power plant. This value takes into account coil-to-meter losses.

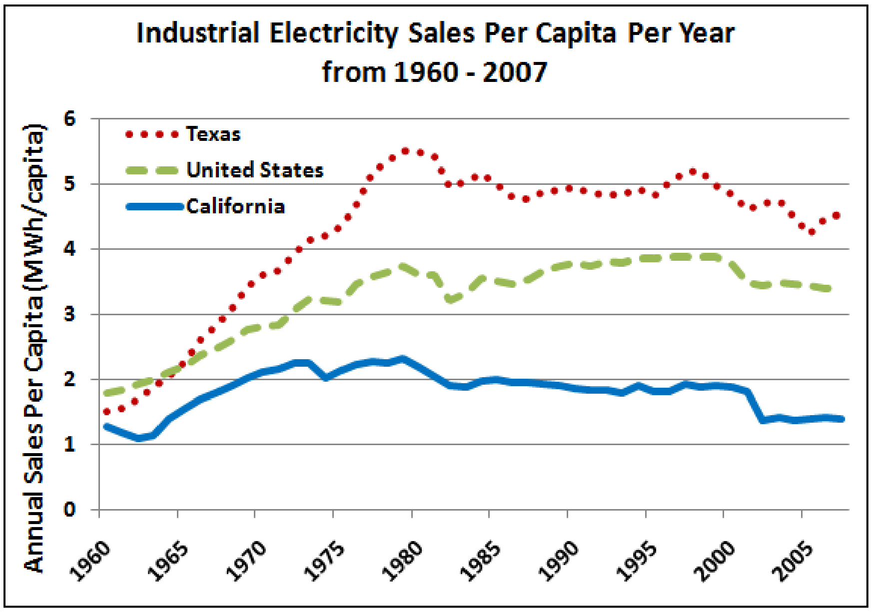



Figure 7: Industrial sector electricity sales on a per capita basis per year from 1960-2007 in Texas, California, and the U.S. show downward trend (22-24)

The Stanford analysis identified three "savings" categories for the industrial sector: industry type, on-site electricity generation, and policy as shown below in Table 3. The third category, possible policy share, was assumed to be applicable for the industrial sector, in general for the same reasons as were outlined in the residential sector discussion in the previous section.

Table 3: Three electricity "savings" categories were identified as potential contributors to the energy efficiency gains seen in California (25)

| | **"Savings" (%)** | **Annual per capita "savings" (ACPS) in kWh** |
|---|---|---|
| **Industrial (2002)** | | |
| Industry Type and size differences | 38.00 ± 3.60 | 1,321 |
| On-site electricity generation differences | 7.40 ± NE | 257 |
| Possible Policy Share | 14.5 | 504 |
| **TOTAL** | **--** | **2,082** |

### 3.6.1 INDUSTRY TYPE

In California, more than one-third of the electricity "savings" identified by the Stanford analysis for the industrial sector was due to industry type. Without choosing to export industries from individual states (an unlikely situation), it would be unwise to simply extend potential "savings" in states due to shifts in the type of industry they have historically played roles in the state's economy. A forced push – for example, due to policy – away from particularly energy-intensive industrial sectors might overlook that the industrial mix of individual states is a function of many factors, which largely develop over time. These factors include natural resources, infrastructure, and labor supply. If the industry within a state were to change due to a variety of cultural, market, or regulatory reasons chooses to make significant changes to its industry type profile, it is unlikely that these shifts could occur on a short time scale. In all likelihood, it makes logical sense that this type of shift would generally take decades to occur because of the workforce and infrastructure development that would be necessary to enable such a change. This slow-moving change means that, at this point, I will not include these potential "savings" in my methodology.

It is interesting to note that, just after China was admitted into the World Trade Organization (WTO) in 2001 there was a distinct and immediate drop in the per capita industrial electricity sales in the United States, as well as California and Texas as shown previously in Figure 7. This trend was seen throughout the United States, as more of our goods shifted from being made in domestic manufacturing plants to being produced in China. (22)(23) (32) The impacts of this shift were felt throughout the states, though in differing degrees.

### 3.6.2 On-Site Generation

California's "savings" as calculated by the Stanford analysis attributed a portion of the "savings" to on-site generation of electricity at higher levels than the United States average. Nationally, the largest manufacturing industries, such as those in Texas (petroleum refining and chemicals) have higher than average on-site electricity production rates. (33) However, it might be possible for other states to recognize significant "savings" through on-site electricity generation using combined heat and power (CHP) or other systems that can utilize waste heat (low-quality steam) to meet some of their electricity needs.

In 2002, just over 15% of national industrial sector electricity needs were met using on-site generation. In California, this number topped 35%. (25) This high level of on-site generation means that significant opportunity to reduce off-site electricity needs for industrial facilities likely exists in states throughout the United States. (33) For the methodology established in this research project, the amount of potential "savings" that can be realized in any given state on an annual per capita basis is determined using equation 7, below. This equation utilizes the fact that California saved annually, on average, 13 kWh per capital per 1% increase in on-site generation.

$$ES_{industrial,on-site\ generation,X} = \left(\frac{13\ kW}{1\%\ increase}\right) \times [(\%\ increase\ onsite\ generation\ in\ state, X) - 15\%]$$

Eq. 7

This equation illustrates an important point regarding the scope that this methodology covers. The equation above provides a measure for the change in electricity sales for a particular region due to on-site generation at industrial facilities. This equation, and this methodology, does not capture total energy "savings" that lie outside of those included in the Department of Energy's total electricity sales category. This means that, on-site and some other types of distributed generation that provide electricity at the point of use are potentially treated as an electricity "savings". However, in a broad sense the only electricity that has been "saved" in these scenarios is that associated with transmission and distribution losses. These losses generally increase with increases in the distance that electrons travel before the energy contained in them are used by the end-use consumer, creating a potential for energy "savings". However, while transmission and distribution losses could be an area for energy efficiency "savings," it was not identified in the Stanford analysis as a potential "savings" category.

### 3.7 Commercial Sector

Historic trends in commercial sector electricity sales per capita, as seen below in Figure 8, show that the stability in California's commercial profile from the mid-1970's until approximately 1998 has now shifted to follow more in-line with national sales values, though still significantly lower in absolute value. Stanford University's analysis of the commercial sector identified two energy efficiency "savings" categories: reduction due to lower floor space intensity and "savings" possibly due to public policy, as shown below in Table 4.

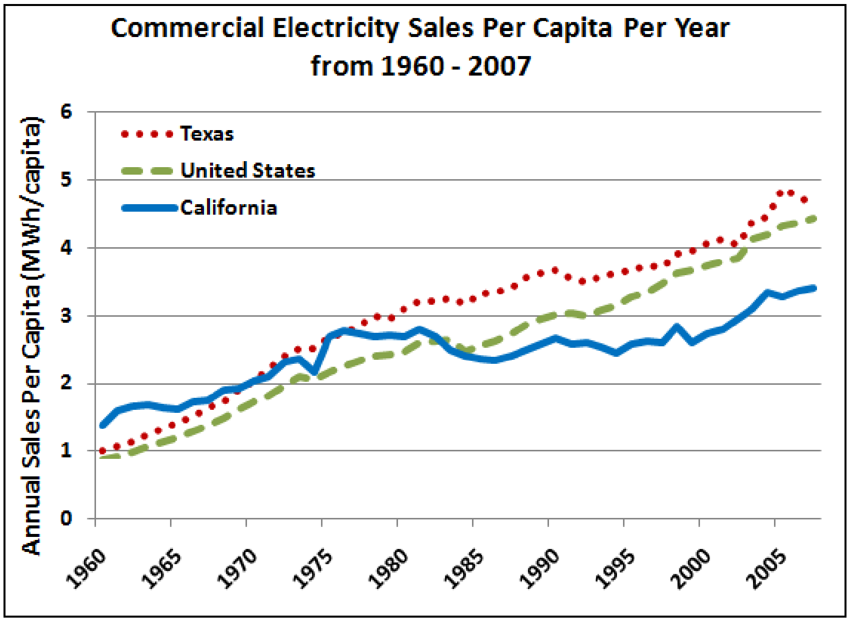



Figure 8: Commercial electricity sales per capita per year from 1960 – 2007 in Texas, California, and the U.S. (22-24)

Table 4: Two categories were identified as potential contributors to the energy efficiency gains seen in California in the commercial sector (25)

| | "Savings" (%) | Annual per capita "savings" (ACPS) in kWh |
|---|---|---|
| **Commercial (2003)** | | |
| Reduction due to lower floor space intensity | 27 ± NE | 1,132 |
| Possible Policy Share | 5.7 | 236 |
| **TOTAL** | **--** | **1,368** |

While the Stanford University analysis found electricity "savings" due to lower floor space intensity of the commercial sector, the increase in annual sales per capita in California since the late 1990s brings to light concerns regarding the applicability of this "savings" category to other states. However, the potential policy share of the energy efficiency "savings" is treated as a valid potential "savings" category to extend to other states because, as previously mentioned in this thesis, the policies implemented in California required increased efficiency in new building construction and appliances while increasing energy use awareness of California electricity consumers. (25) These "savings" from policy mechanisms is believed to be reasonable to implement in other states.

### 3.8 Extending the Rosenfeld Effect to Texas

In the previous section, each "savings" category identified by Stanford University's analysis of the Rosenfeld Effect in California was examined to establish a methodology for extending energy efficiency "savings" to other states or regions. This section discusses the application of this methodology to the state of Texas, in order to establish a reasonable level of efficiency "savings" that could be achieved in Texas for the purpose of the tradeoff analysis that will be discussed later in this thesis. The results of this analysis are referred to as the potential for recreating the Rosenfeld Effect in Texas.

These results will later be compared to publications released by the Public Utility Commission of Texas (PUCT) and the American Council for an Energy-Efficient Economy (ACEEE) regarding potential "savings" from energy efficiency in Texas. (26) (27) By comparing these results, we are able to see the relative levels of potential energy efficiency "savings" predicted by the methodology that I developed using the Rosenfeld Effect as a basis for evaluation, versus what other organizations have designated as reasonable efficiency gains for Texas. The differences between these values for reasonable efficiency gains in Texas s particularly interesting in that it helps to construct a range of potential energy efficiency "savings" limits for Texas that can be used to evaluate the feasibility of policy proposals and other plans that include energy efficiency guidelines and requirements.

First, I will address energy efficiency potential for the Texas residential sector. Energy efficiency from heating and cooling load reductions in Texas was calculated using equation 8, below in units of kWh referring to the total number of kWh that can be "saved" on average per year per capita.

$$EESP_{cooling,R} = [1{,}242 - 2{,}477] \times \left(0.66 \, {}^{kW}\!/_{CDD}\right) = -815 \, kW$$

Eq. 8

Due to Texas's hot climate and corresponding increased need for electricity for cooling, the calculation above shows that Texas's energy efficiency "savings" potential is in fact negative. This high level of cooling degree-days means that Texas will likely be unable to realize cooling load reductions due to climate. This inability to realize "savings" because of a relatively hot climate does not mean that the state cannot reduce its electricity use for cooling by promoting more efficiency cooling technologies in the residential sector.

Heating load reductions due to the Texas climate tells a different story than cooling load. With an average of 2,286 heating-degree days compared to a national average of 4,524, Texas might be able to recognize significant energy efficiency "savings" due to climate. The state might also be able to realize electricity "savings" by switching consumers to natural gas, fuel oil, or other heating technologies. The potential "savings" due to the Texas winter climate is calculated, as described previously in the methodology section, using Equation 9 and units of kWh on average per person per year:

$$EESP = [4{,}524 - 2{,}286] \times \left[0.26 \, {}^{kWh}\!/_{HDD}\right] = +582 \, kWh$$

Eq. 9

While Texas might be able to recognize energy efficiency “savings” due to heating load reduction because of its mild winter climate, the harsh summers (as represented by a high number of cooling-degree days) still give a negative net result in climate control load due to climate. In other words, Texas needs a lot of energy to cool homes during the year and this energy requirement offsets the “savings” realized by the comparably mild winters.

As described in the methodology section, energy efficiency potential due to fuel choices for water heating can be extended in the absence of policies that prevent the use of natural gas for water heating in the region. Since Texas does not have such policies, beyond isolated cases in cities including Austin that historically prevented houses from using natural gas in homes, this “savings” of 238 kWh on average per person per year is extended to Texas. (25)

With respect to household size (HHS), Texas has an average household size of 2.81, slightly less than California’s 2.87 average. Applying this value to Equation 10 provides an energy efficiency “savings” potential for Texas, as shown below in units of kWh on average per person per year:

$$ES_{HHS,R} = (2.81 - 2.6) \times 1{,}415 = 297\ kW$$

Eq. 10

This 297 kWh value shows that Texas might be able to realize significant energy efficiency “savings” due to increased household sizes compared to the United States’ average.

In the industrial sector, energy efficiency “savings” due to policy mechanisms can be extended to Texas for reasons previously discussed in this thesis. However, due to Texas’s energy-intensive petroleum refining and chemical plants, energy efficiency “savings” in these categories might not be realistic if extended to Texas. With respect to on-site generation, California's "savings" as calculated by the Stanford analysis attributed a portion of the "savings" to on-site generation of electricity at higher levels than the United States average. Nationally, the largest manufacturing industries, such as those in Texas (petroleum refining and chemicals) already have higher than average on-site electricity production rates. (33)

For the methodology established in this research project, the amount of potential "savings" that can be realized in any given state on an annual per capita basis is determined using equation 11, below. This equation utilizes the fact that California "saved" annually, on average, 13 kWh per capita per 1% increase in on-site generation.

$$ES_{industrial,on-site\ generation,X} = \left(\frac{13\ kW}{1\%\ increase}\right) \times [(\%\ onsite\ generation\ in\ state, X) - 15\%]$$

Eq. 11

At this time I have been unable to find a reported value for the percentage of total electricity supplied via on-site generation in Texas in the same format that was provided Stanford analysis. Therefore, for the purpose of this analysis I will not extend potential energy efficiency "savings" to Texas for this category.

Regarding the commercial sector, as mentioned in the methodology discussion only "savings" that might be achievable due to policy mechanisms will be included as potential energy efficiency "savings". Therefore, I will only state a potential "savings" of 236 kWh on average per person per year for Texas. The summary of this and the other two electricity use sectors are summarized below in Table 5.

Table 5: Rosenfeld Effect potential annual per capita electricity “savings” (kWh/capita-year) in Texas (25)

| | **Annual per capita “savings” (APCS) in kWh** | **Electricity “Savings” (%)** |
|---|---|---|
| **Residential** | | |
| Cooling load reduction | -815 | -6% |
| Heating load reduction | 582 | 4% |
| Water Heating load reduction (fuel choices) | 238 | 2% |
| Household Size | 297 | 2% |
| Possible Policy Share | 545 | 4% |
| **Industrial** | | |
| Possible Policy Share | 504 | 4% |
| **Commercial** | | |
| Possible Policy Share | 236 | 2% |
| **TOTAL** | **1587** | **11%** |

The electricity “savings” (ES) shown above in Table 5 were calculated using Equation 12, below. In this equation, I used 2007 per capita electricity sales (PCES) of 14.4 MWh to determine the percent “savings”.

$$ES = \frac{APCS}{PCES_{2007}}$$

Eq. 12

The results shown in Table 5 (above) show that, despite the detrimental impact of increased electricity needs due to the hot Texas climate, the state might be able to realize up to 11% per capita annual electricity “savings” due to energy efficiency. As is shown in the next two sections, this total “savings” value appears to be an aggressive estimate compared to other organizations’ published values for energy efficiency potential in Texas.

This apparent discrepancy brings to light an interesting consideration when it comes to the discussion of a state's ability to recreate the Rosenfeld Effect. Throughout this thesis the potential in Texas to realize energy efficiency "savings" in the same manner in which California might have realized the "savings" that led to the Rosenfeld Effect has been analyzed. However, it is realistic to believe that Texas might have already realized "savings" in the categories identified by the Stanford analysis. The energy efficiency potential in Texas that has already been realized might explain the relatively high potential for energy efficiency "savings" identified in this analysis, compared to the estimates of other organizations as discussed in the following sections.

### 3.9 Public Utility Commission of Texas Energy Efficiency Estimates

The Public Utilities Commission of Texas (PUCT) released a report in December 2008 regarding the potential for electricity "savings" in Texas from energy efficiency programs. (26) The PUCT analysis estimated the technical, economic, and achievable energy efficiency potential in Texas to verify the reasonableness of energy "savings" goals set in the state. The study focused on the nine Investor Owned Utilities (IOUs) in the state. These IOUs provided over 322 terawatt-hours (TWh) (or 93% of the total) in electricity sales across all sectors (residential, commercial, and industrial) in 2007.

This study found a cumulative annual electricity "savings" economic potential from energy efficiency of 12 TWh across all sectors with baseline program funding. Aggressive efficiency program funding would lead to 20 TWh of cumulative annual economic energy efficiency savings in 2018. (26) These 12 to 20 TWh would replace 2.7% to 4.5% of the total projected electricity sales in Texas in 2020. Using previously discussed population projections for Texas by the U.S. Census Bureau, this total savings corresponds to an annual per capita electricity savings of 0.4 to 0.7 MWh. These savings estimated under the assumption that energy efficiency measures would be supported or required via some external mechanism, likely a mandate or other policy tool. These estimates are much smaller than those predicted using the Rosenfeld Effect methodology developed in this thesis, indicating that the potential for recreating the Rosenfeld Effect in other states may be an aggressive prospective task. Alternatively, it could indicate a conservative approach on the party of the PUC in evaluating energy efficiency potential in Texas.

### 3.10 American Council For An Energy-Efficient Economy Energy Efficiency Estimates

A report published by the American Council for an Energy-Efficient Economy (ACEEE) in March 2007 concluded that approximately 10% of 2020 electricity use in Texas could be met using energy efficiency programs. These savings were dependent on a set of six policies, which ACEEE believes are likely to be politically viable in Texas. These policies include (27):

1. Expanded utility-sector energy efficiency improvement programs
2. New state-level appliance and equipment standards
3. More stringent building energy codes
4. Advanced energy-efficient building program
5. Energy-efficient state and municipal building program
6. Short-term public education and rate incentives

With the projected 2020 electricity use in Texas of 430 TWh as stated in the ACEEE report, this potential electricity savings in 2020 corresponds to 43 TWh or 1.5 MWh per capita per year using the population projections from the U.S. Census Bureau previously used in this analysis. (34) Using the net sales projection of s 43 TWh in 2020, this corresponded to 9.6% of the total sales in 2020.

These recommendations were developed under the overarching goal of reducing peak demand in Texas in order to reduce the amount of new generation capacity needed while simultaneously reducing the overall electricity demand in the state, relative to projected future demand levels. The authors of this report included population growth considerations in their discussion, acknowledging that this, coupled with the expanding Texas economy, could work against increasing energy efficiency in the state. (27) The energy efficiency "savings" values presented by ACEEE are again lower than those calculated in this thesis using the Rosenfeld Effect methodology. This could indicate that the recreating the Rosenfeld Effect in other states might be an aggressive proposition.

### 3.11 CONCLUSION

This Chapter discussed the development process for a methodology for extending the Rosenfeld Effect to other states or regions. This methodology was broken down by sector (residential, industrial, and commercial) and "savings" category (for example, heating load reductions and possible policy impacts). The Chapter then discussed the application of this methodology to the state of Texas, which outputted an annual per capita energy efficiency potential "savings" of 11%. This value appear high compared to published values by the Public Utility Commission of Texas (PUCT), which reports a 2.7% to 5.4% range for the state's energy efficiency "savings" potential. It is also much higher than the 9.6% energy efficiency "savings" potential reported by the American Council for an Energy Efficient Economy (ACEEE).

# Chapter 4: The Texas Interactive Power Simulator

## 4.1 Overview

The Texas Interactive Power Simulator (TIPS) is an interactive analytical tool developed to quantitatively compare the first-order economic and environmental tradeoffs of different electricity production methods in Texas. The tool was designed for analysis of different power choices and was presented in an online format for use by students, the general public, and government decision-makers including members of the Texas legislature.

The Texas Interactive Power Simulator provides a framework and methodology for assessing the tradeoffs of electricity generation technologies in terms of economic costs and environmental impacts. Economic costs include major factors such as the cost of capacity, fuel, operation and maintenance (O&M), as well as the costs of conservation programs and environmental impact mitigation technology. Environmental impacts include market externalities such as the environmental impacts on air, land, and water, and are normalized per kWh generated (for example, pounds of $CO_2$ or NOx, acres of land, or gallons of cooling water consumed per kWh of electricity generated).

The core electric industry data used by the Texas Interactive Power Simulator were Texas-specific, but the flexibility of the framework, when combined with user-supplied content, extends the applicability of this tool to the United States and world electricity markets. Users can supply their own data for interactive experimentation, though peer-reviewed data are provided as default values.

The Texas Interactive Power Simulator backend was designed using LabVIEW software to allow the user to virtually change the electricity generation mix in the state of Texas in terms of the percentage of total generation from each generation source. Total generation is determined using electricity demand inputs as described in subsequent sections. The user may specify generation technologies (e.g. Pressurized Water Reactor, wind turbine, etc) that they wish to incorporate, or may choose from a more general set of categories which refer to the specific fuel source (e.g. coal, nuclear). In the latter case, TIPS utilizes representative average values for economic costs and environmental impacts based on the current Texas electricity generation mix. In the following sections, I will discuss the inputs and outputs used by TIPS, as well as the mathematical equations used in all calculations.

### 4.2 INPUTS

The Texas Interactive Power Simulator allows the user to enter values that will determine the electricity demand in 2030 and the ways by which that demand will be met. In order to determine the 2030 electricity demand, the user enters either 1) the annual demand growth rate (%/year) or 2) the population growth rate (%/year) combined with annual per capita energy consumption. The second method was provided because of the inherent tie between total electricity consumption and population (people consume electricity, more people consume more electricity) combined with the evidence leading to the Rosenfeld Effect, which shows that per capita electricity use can be stabilized under certain conditions, as discussed in Chapter 3.

The user is also able to input how the electricity demand in 2030 is to be met. Choices can be made according to fuel (coal, natural gas, nuclear, wind, hydro, solar, or biomass) or technology. For coal-fired power plants, the user could choose that demand be met using pulverized coal (PC) or integrated gasification combined cycle (IGCC) technology. For power plants using natural gas, users may select from natural gas combined cycle (NGCC), natural gas - steam turbine (NGST), or natural gas - gas turbine

(NGGT). Nuclear power technologies were limited to current boiling water reactor (BWR) designs and pressurized water reactor (PWR) designs. With respect to wind turbine technologies, users may select on- or off-shore wind facilities, which impacts the capacity factor used for calculating annual power output. Solar technologies included in the TIPS input range were photovoltaics (PV) and concentrated solar power (CSP). Biomass technologies were generalized to a single technology option because of the wide-variability depending on energy inputs.

### 4.3 OUTPUTS

TIPS' outputs include text and graphics showing the electricity output and environmental impact of the user's selections, which allow the user to interpret the overall impact for different fuel mixes. Source data are incorporated from government sources and peer reviewed technical literature. The TIPS interactive interface allows the user to analyze a desired electricity mix according to the percentage breakdown of electricity production for each generation technology. The user input determines the overall direct and indirect costs of a unit of electricity according to the particular cost parameters associated with each generation technology. This thesis discusses the methodology used in TIPS calculation and shares the results of using TIPS to analyze the cost and environmental impacts for a variety of illustrative and possible generation scenarios in Texas, including the following: high carbon prices, nuclear renaissance, and continuing wind market growth.

## 4.4 Electricity Generation Technologies By Primary Fuel Type

The Texas Interactive Power Simulator allows the user to specify the general category of fuel (e.g. coal) or the specific technology (e.g. IGCC) that they would like to select to generate the chosen percentage of total generation. If they select the category of fuel without specifying the technology, representative values are used based on the current breakdown in Texas. The fuel choices provided to the user in this tool are coal, natural gas, nuclear, wind, hydro (water), and solar. If the user chooses to select specific technologies, they have a large set of choices for each fuel type, including:

1. Coal – pulverized coal (PC), integrated gasification combined cycle (IGCC)
2. Natural gas – natural gas combined cycle (NGCC), natural gas steam turbine (NGST), and single-cycle natural gas gas turbine (NGGT)
3. Nuclear – boiling water reactor (BWR), pressurized water reactor (PWR)
4. Wind – onshore wind
5. Hydro – large hydroelectric dams
6. Solar – photovoltaics (PV), concentrated solar power (CSP)

## 4.5 Capacity Factor

Most electricity generation technologies have established capacity factors (CF) determined from historical performance and functional limits of the equipment. These values are based on the operation and maintenance requirements of a power plant facility, or the available of fuel, as is generally the case with renewable fuel sources. The capacity factor indicates the percentage of the year during which the power plant facility can generate electricity at full capacity. This relationship is shown below in equation 13, where “Generation” refers to the total amount of electricity that the power plant will generate in a given year in units of megawatt-hours (MWh), given a capacity rating in megawatts (MW):

$$Generation = (Capacity) \times \left(8{,}760\,\frac{hours}{year}\right) \times CF$$

Eq. 13

For example, a 500 MW (capacity) coal-fired power plant with a capacity factor of 85% can practically run at full capacity for a total of 310 days out of the year, the other 55 days likely being devoted to plant maintenance or the cycling down of the plant due to decreased demand for certain hours of the day, or can run at 85% capacity for all 365 days.

## 4.6 Environmental Impacts

Environmental impacts that result from power plant operations were placed in three categories: air emissions, water consumption, and land required for the power plant footpr

*int. The environmental impact values used in th Texas Interactive Power* Simulator were non-lifecycle, including only the environmental impacts at the point of generation. Lifecycle values were not utilized because of the very small magnitude of the environmental impacts not associated with generation for most of the technologies and fuels. The variability of environmental impacts when measured for the entire lifecycle makes it inappropriate to use in the Texas Interactive Power Simulator, given the generalizations used for each fuel type in terms of origin.

Air emissions refer to the emission of carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and sulfur dioxide ($SO_2$) emitted into the air at the point of generation (i.e. the power plant). Water consumption does not include the total water requirements of the plant – referred to as pass-through water use – but only includes the water that is evaporated and emitted into the outside air during cooling. Land impacts refer to the amount of land (in acres) that is required for the siting of the power generation facility. This value does not take into account the potential for dual-use of land.

### 4.7 DETERMINING FUTURE ELECTRICITY GENERATION REQUIREMENTS

In order to determine the electricity demand in 2030, the user is required to enter one of the following combinations of options: the annual electricity demand (in megawatt-hours or MWh) growth rate (%/year) or a combination of the population growth rate (%/year) and annual per capita energy demand (MWh/year) for the analysis period. This mode is utilized in all analysis and discussion provided in this thesis.

Electricity generation from the current year to 2030 is calculated based on user inputs. It should be understood that the term electricity generation refers specifically to the amount of electricity required during the year by the end use customer in addition to the amount of electricity lost during transmission and distribution of this electricity.

The user may enter either the demand growth rate (%/year) or the population growth rate (%/year) and a corresponding per capita electricity demand value. Should the user chose the first option, the electricity generation over time is calculated using Equation 14, electricity generation ($EG_t$) versus time for a specified annual growth rate (AGR, %/year):

$$EG_t = EG_0 \times (1 + \frac{AGR}{100})^t$$

Eq. 14

$EG_0$ refers to the electricity generation at time (t) equal to 0, which is the case in 2009. The electricity generation in the year 2030 is represented above as $EG_{21}$ (21 indicating the number of years after 2009). Alternatively, the electricity demand may be calculated using the annual population growth rate (%/year) and per capita electricity demand ($\mathrm{MWh/person \cdot year}$) which is assumed to equal the electricity generation rate when multiplied by the population size. In this case, the electricity generation requirement is calculated using Equation 15, electricity generation versus time for a specified annual population growth rate (APGR) and per capita electricity demand (PCED).

$$EG_t = Total\ Population\ \times PCED \times (1 + \frac{APGR}{100})^t$$

Eq. 15

Per capita electricity demand is assumed constant, but will change over time in future versions due to the potential value of this degree of freedom. As with electricity generation (EG) requirements, per capita electricity demand refers to the amount of electricity generation required by each person, taking into account losses during the transmission and distribution of this electricity. Default values for the previously discussed inputs are not provided to the user at this time.

### 4.8 DETERMINING LEVELIZED COST OF ELECTRICITY (LCOE)

Economic costs were measured in terms of two categories: cost of new capacity and levelized cost of electricity (LCOE). New capacity cost (NCC) includes the capital investment required to build any new power plants required by the generation mix the user specifies as shown below in Equation 3 using the capacity factor (CF, expressed as a percent) for each technology. If this value is negative, then the new capacity cost is zero.

When positive, the new capacity required was multiplied by the capacity cost (CC) as shown in Equations 16 and 17 below, which calculate new capacity cost for a technology or fuel category (*j*).

$$NCC_j = [\mathrm{TC} - \mathrm{EC}]*\mathrm{CC}$$

Eq. 16

$$= \left[\left(\frac{TG_j}{CF_j/100}\right) - \mathrm{EC_j}\right] * CC_j$$

Eq. 17

New Capacity Cost (NCC) is summed for all technologies (or fuels) to determine the total new capacity cost (TNCC). In TIPS calculations, the existing capacity values shown below in Table 6 are used for fuel categories.

Table 6: Existing Capacity for Fuel Sources in Megawatts (MW) (7)(35)

| | **Coal** | **Natural Gas** | **Nuclear** | **Wind** | **Hydro** | **Solar** |
|---|---|---|---|---|---|---|
| **Existing Capacity (MW)** | 21,381 | 71,737 | 5,138 | 8,100 | 674 | 0 |

The user inherently chooses the MWh/year for each technology by firstly dictating the total MWh/year by specifying a demand growth rate and secondly choosing the percentage of electricity from each fuel/technology category. There is no feedback mechanism for modifying the user's inputs based on the resulting levelized cost of electricity (LCOE) values calculated. Rather, the LCOE is strictly calculated using the input values given by the user for the generation mix. Levelized cost of electricity is calculated using Equations 18, 19, and 20 below. Costs and impacts are non-lifecycle costs, selected as a representative value from within a range of published costs for all included technologies. All monetary values are expressed in 2009 dollars.

$$LCOE = \frac{CC + IDC(r, N_{constr}, IC) + PV(i, N_{yrs}, \text{O\&M + fuel + externalities})}{PV\left(i,\ N_{yrs}, C_{total}\right) \times ({}^{MW}/_{yr})}$$

Eq. 18

where

$$PV\left(i, N_{yrs}, C_{total}\right) = \frac{C_{total}}{i/100}\left[1 - \frac{1}{(1 + i/100)^{N_{yrs}}}\right]$$

Eq. 19

and

$$IDC(r, N_{constr}, IC) \approx IC \cdot (r/100) \cdot N_{constr}$$

Eq. 20

Note that equation 18 is an approximate value because this equation does not take into account the effect of compounding of interest.

## 4.9 CALCULATING ENVIRONMENTAL IMPACTS

Air emissions and water consumption were calculated on a per megawatt-hour basis similar to the cost calculations previously described. Values were calculated for a weighted average megawatt-hour of generated electricity. Environmental impacts from power plant operations are characterized in two categories: air emissions and water consumption. Air emissions include carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), and Nitrogen Oxides ($NO_x$) emitted during plant operation. Water consumption does not refer to the total amount of water used for power plant cooling (pass-through water use), but specifically refers to the amount of water that is consumed during this process (consumptive water use).

Air emissions and water consumption are calculated on a per megawatt-hour basis. Environmental impact values are weighted according to the generation mix used to generate each unit of electricity, according to the fuels or technologies that are included in the mix. For instance, a generation mix that is 50% coal power and 50% nuclear power will have an air emissions factor that is the sum of 50% times the air emissions associated with coal power and 50% times the air emissions factor associated with nuclear power.

As with economic costs, environmental impact values do not account for the full power plant life cycle. For instance, quantifying the full externality of disposing spent nuclear fuel or the air emissions released during power plant construction was not attempted. Research showing the impacts of the manufacturing and construction phases of electricity generation equipment, for example life cycle greenhouse gas emissions, shows that those with no direct emissions emit 1-2 orders of magnitude less.(36) Thus, while valuable for research and technology development, for the target audience of this initial version of TIPS, the lifecycle impacts from indirect energy and emissions are not currently of high value. Values for environmental impacts are determined using Equation 21, which calculates the average environmental impact (*ei*) to determine the average environmental impact per MWh.

$$ei = \sum_{j} (\%Generation)_j \ * \left(\frac{amt.\,of\ pollutant\ or\ resource\ use}{MW}\right)_j$$

Eq. 21

Note that values for this calculation are populated from Table 7 (below). Total emissions per year (*EI*) are found by multiplying the environmental impact (*ei*) by the total annual generation as shown below in Equation 22.

$$EI = ei * EG_t$$

Eq. 22

Table 7: The input data used in the Texas Interactive Power Simulator calculations, by fuels (37-45)

| | **Coal** | **Natural Gas** | **Nuclear** | **Wind** | **Hydro** | **Solar** |
|---|---|---|---|---|---|---|
| **Cost of Capacity (million$/MW)** | 1.5 | 0.9 | 5.0 | 2.5 | 1.7 | 5.0 |
| **O&M Cost* ($/MWh)** | 5 | 5 | 15 | 10 | 10 | 9.5 |
| **Fuel Cost ($/MWh)** | 15 | 80 | 5 | 0 | 0 | 0 |
| **$CO_2$ Emissions (lbs/MWh)** | 2293 | 1146 | 0 | 0 | 0 | 0 |
| **$SO_2$ Emissions (lbs/MWh)** | 6.8 | 1 | 0 | 0 | 0 | 0 |
| **$NO_x$ Emissions (lbs/MWh)** | 5 | 0.03 | 0 | 0 | 0 | 0 |
| **Water Consumption (gal/MWh)** | 426 | 223 | 600 | 0 | 0 | 0 |
| **Land Use (acres/MW)** | 1.2 | 0.05 | 0.05 | 25 | 131 | 4.6 |
| **Capacity Factor** | 84 | 80 | 90 | 26 | 22 | 25 |
| **Construction Timeline (years)** | 8 | 8 | 15 | 2 | n/a | 2 |
| **Economic life (years)** | 30 | 30 | 40 | 15 | n/a | 20 |

## 4.10 OVERVIEW OF THE TEXAS INTERACTIVE POWER SIMULATOR

The Texas Interactive Power Simulator gives educators the ability to compare quantitatively the economic costs and environmental impacts of electricity production methods according to fuel source (i.e. coal, natural gas, nuclear, wind, sun, water). The simulator's interactive interface allows the user to set a desired mix of fuels according to the percentage breakdown of electricity production. Based on these inputs, the Texas Interactive Power Simulator determines the overall direct costs and indirect impacts of a unit of electricity according to the costs associated with each fuel type. These measures provide students, teachers, and other users with transparent and unbiased methods for understanding basic tradeoffs that emerge from different fuel mixes.

TIPS also provides a level of basic education on electricity generation. Beyond cost and environmental impact information, the Texas Interactive Power Simulator generates graphs and charts to effectively communicate the differences between electricity production methods via the unique characteristics of each. These educational lessons can be applied to many electricity markets and provide an introduction for those who wish to become proficient in the field. Portions of the TIPS website are specifically designed for classroom use regarding the topic of electricity production in Texas. However, the simulator's flexible framework lends itself to easy expansion to cover the fuel mix for other regions, including the entire US and world markets.

## 4.11 USER INTERFACE DESIGN

The user interface for the Texas Interactive Power Simulator was designed to enable the effective communication of key lessons to the user. The initial portal into the website is displayed below in Figure 9 and is used to provide background information and collect statistical data about the user as described in later sections.

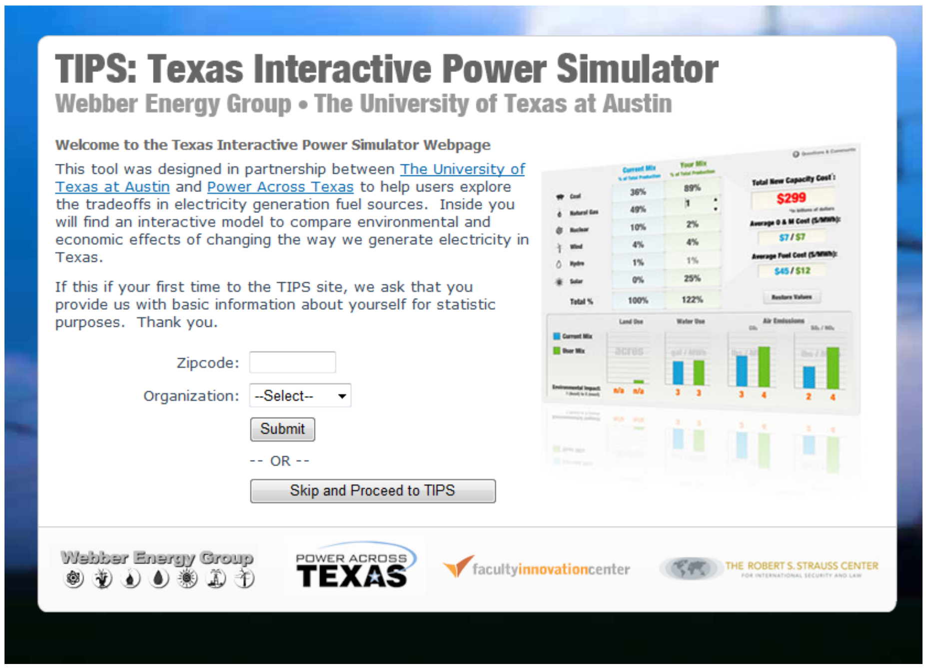



Figure 9: Welcome Page

The Texas Interactive Power Simulator tutorial page allows users to self-teach components of the model's back-end calculations and user interface displays. There are links to three documents: a detailed tutorial, functionality overview, and key technical bullet points. The tutorial page, shown below in Figure 10 is also linked to the main model interface page shown in Figure 10.

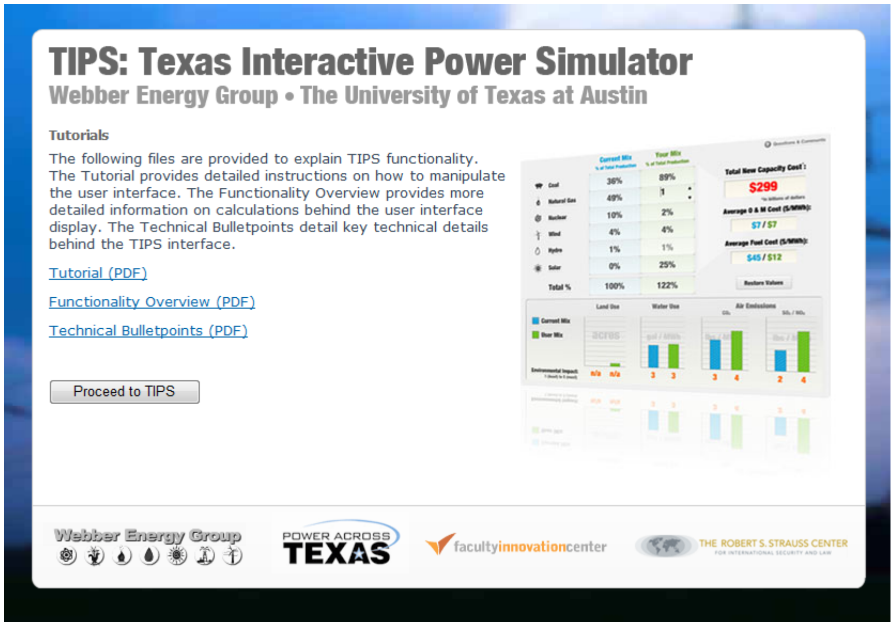



Figure 10: Tutorial Page

The tool itself is accessed by selecting the “Proceed to TIPS” button showed in Figure 10, which brings the user to the model interface page. On this page, the user may manipulate the values listed under the “Your Mix” column with the exception of the percent of generation from hydroelectric power sources, which as previously mentioned is fixed at 1% of the total 2007 generation. As the user changes the generation mix, the resulting environmental and economic effects are automatically updated in real time.

Economic impacts are displayed on the right hand side of the user interface in numerical form. Environmental impacts are displayed on the bottom portion of the screen in graphical form. The first graph displays land use for the “Current Mix” and “Your Mix.” Similarly, water use and air emissions are displayed to the right of the land use graph. All graphs are scaled to accommodate the maximum and minimum values producible by “Your Mix.” Below the environmental impacts graphs is an environmental impact ranking system.

All model output values resulting from the user's changes are displayed in green throughout the webpage with the exception of total new capacity cost displayed in red. Values for the "Current Mix" are fixed and displayed in blue to provide users with an easy way to compare the differences between their customized "Your Mix" and the "Current Mix". The model's interface design is displayed below in Figure 11.

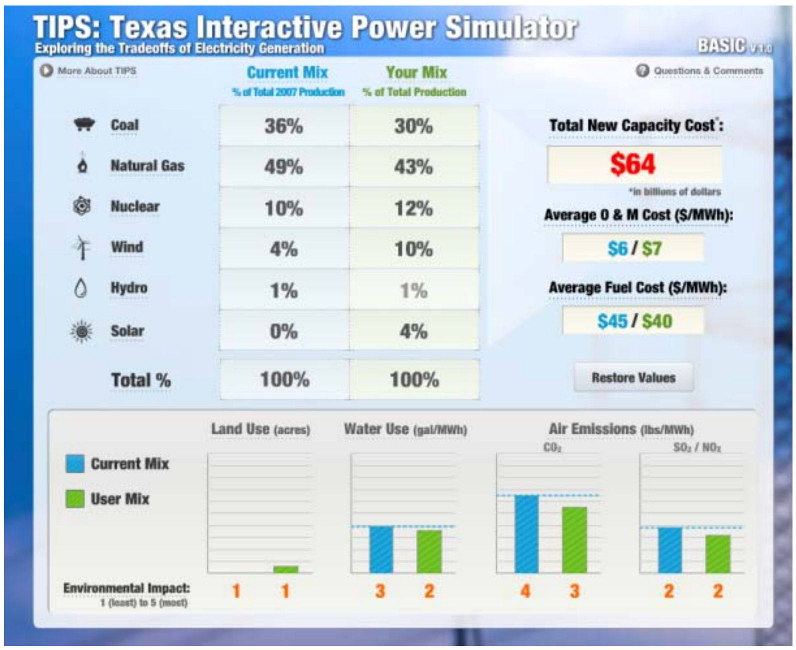



Figure 11: Model Interface Page

As the user changes values for percent of total electricity generation, the Texas Interactive Power Simulator displays the altered impacts in real time. Example outputs of the model are displayed in Figures 5 and 6 by using the following inputs from the user's "Your Mix" scenario: 30% of total generation from coal, 43% from natural gas, 12% from nuclear, 10% from wind, 1% from hydro, and 4% from solar. Figure 12 shows the economic impacts display for this scenario. For the example scenario, a $64 billion cost for new capacity is required to meet the 6% increase in wind and 4% increase solar electricity generation. Negative costs are not included for the decrease in natural gas and coal generation. A drop in average fuel cost from $45 to $40 per megawatt-hour is also seen. This drop is the result of the decrease in generation from natural gas ($80/MWh fuel cost) coupled with an increase in generation from wind and solar ($0/MWh fuel cost). For this scenario, average operation and maintenance cost also rose from $6 to $7 per megawatt-hour, primarily due to the decrease in coal generation and increase in wind generation. These results are displayed below in Figure 12.


Figure 12: This image gives us a snapshot of how the economic costs are displayed.

Environmental impacts are displayed using graphs and an environmental impacts ranking system. The land use graph displays the impact ranking for the total amount of land required for the indicated generation mix, including all currently used land. The water use and air emissions graphs show the impact ranking based upon the weighted average values of the fuel-specific environmental impact values in Table 13.

The environmental impacts ranking system were used to provide users with a feel of how the generation mix in Texas currently compares to the least and most environmentally impactful scenarios. The ranking system used a value of one for the least impactful scenarios and a value of five for the most impactful scenarios. To explain the ranking system, the water use category is used as an example. Because nuclear power has the highest water consumption factor, maximum consumptive water use occurs with a generation mix 100% nuclear power and 0% from all other fuel sources. This scenario would provide a maximum value for water use of 600 gallons per megawatt-hour generated. A ranking of "5" is defined as 80-100% of this 600 gallons per megawatt-hour value. A ranking of "4" is defined as 60-79% of this value and so forth.

The environmental impact graphs and rankings are displayed below in Figure 13 for the aforementioned example scenario. The decrease in water use and air emissions per megawatt-hour generated in the example scenario versus the "Current Mix" results in a drop in ranking from a 3 to 2 in water use and a 4 to a 3 in air emissions for carbon dioxide. While an appreciable decrease in air emissions of sulfur dioxide and nitrogen oxides also occurs, the change is not significant enough to result in a decrease in environmental ranking. Blue bars were used to represent the "Current Mix" and green bars are used to represent example scenario "Your Mix". Taller bars indicate increasing environmental impact for that category.


Figure 13: This image gives a representative snapshot of how the environmental impacts are ranked and displayed.

### 4.12 FEEDBACK TO USER

If the user-selected mix may lead to problems with meeting base or peak load requirements during the year, a warning flag appears to alert the user that problems may arise with their chosen generation mix. Additionally, the user input that is the root of the potential problem is shaded yellow to remind the user that this value may provide difficulties in a real generation mix scenario. An example of a warning issued by the program may be seen below in Figure 14. This particular warning is issued in the case where the user requests more wind than is acceptable without backup peaking power.

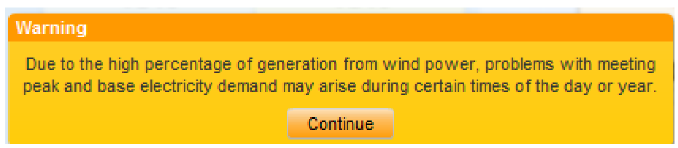



Figure 14: Warning flags are used to alert the users to fuel mixes that might not meet demand requirements.

### 4.13 USER DATA COLLECTION

TIPS directly collected user data regarding their geographical location in the United States according to their zip code as well as their organization type (academia, industry, government, military, or other). These data are gathered on the TIPS welcome page as previously shown in Figure 9. Google Analytics is also used to monitor use of this tool.

### 4.14 CLASSROOM USE

The goal for using the Texas Interactive Power Simulator in the classroom is twofold. First, it allows students to become exposed to the key topics regarding the tradeoffs of electricity generation technologies. Second, it allows the developers to gather important pedagogical information that will enhance future versions in terms of its teaching abilities. The theoretical framework behind the Texas Interactive Power Simulator draws from work by Erwin Boschmann regarding using technologies in secondary and higher education as well as industrial and government organizations. (46)

At the University of Texas at Austin, TIPS was used for direct instruction in two freshman courses. The first course is an undergraduate seminar course targeted toward first year engineering students with an interest in aspects of energy, technology, and policy. The second course is targeted toward a non-technical audience as an interdisciplinary undergraduate studies course predominantly consisting of first-year students.

### 4.15 DIRECT INSTRUCTION FEEDBACK SURVEY

The assignment was developed by the instructors and teaching assistants for the course, two of whom had extensive experience with the Texas Interactive Power Simulator. Questions were developed that would guide the students through all sections of the website including the embedded fuel technology datasheets. Seven questions were asked, from each of the following learning modules: electricity generation mix (2 questions), air emissions impacts (1 question), water use (1 question), land use (1 question), total generation data (1 question), term definitions (1 question). This distribution of questions forced the students to explore all aspects of the tool including the main interface, pop-up information bubbles, and fuel technology datasheets. By exposing the students to each of these, they can then be reasonably expected to expand upon this basic functional understanding of the TIPS website to answer many more questions.

After completing the homework assignment (see Appendix B.4), they were given a survey regarding their impressions of the website. The survey was not targeted at evaluating the specific knowledge that the students gained while using the website, but instead was geared toward impressions and feelings that the students developed during website use. The survey with compiled responses is shown in Appendix C.4. Out of the responses provided by the seventy students who were surveyed, seventy-six percent said that they liked using the tool and eighty-two percent expressed a desire to have more tools like this to use to understand energy concepts.

A distinct majority (95%) of the respondents believed the website to be credible. Comments included “I believe this website was credible because it included lots of citations and data” as well as “this website belongs to the University of Texas at Austin, so I believe it should be credible.” Those who were uncertain as to the credibility of the website credited their uncertainty with the general technical structure of the tool itself as indicated by the comment “I couldn’t use the tool easily and so couldn’t decide if it was credible” and “the information was hard to find, so it might not be credible.” In subsequent informal discussions with the students, it was apparent that having the University of Texas at Austin as the website creator produced a large effect on the perception of credibility of the site. Though not directly tested there was a strong indication from the students that a non-academic creator would have elicited more skepticism as to credibility.Future studies using students at other institutions of higher learning can test a potential bias of those enrolled at the University of Texas.

Ninety-three percent of respondents believed that the Texas Interactive Power Simulator is a valuable learning tool for those interested in the tradeoffs of electricity generation. Ninety-four percent of those surveyed thought it was a useful tool for specifically teaching lessons on the economic and environmental tradeoffs of electricity generation methods in the state of Texas.

Seventy-six percent of users liked using the Texas Interactive Power Simulator website. Of the twenty-four percent who did not enjoy using the site, frequent comments included a lack of enjoyment due to the website layout and lack of clarity of information presented. One respondent specifically commented that they "couldn't figure out how to use the chart… couldn't figure out how to use it." Of those who liked using the TIPS website, frequent comments included a surprise at how easily they grasped new concepts and gained knowledge on the current state of the Texas electricity generation landscape. Comments such as "I can't believe we use so much natural gas" and "the environmental effects were easy to see… I had no idea nuclear used a lot of water" were included in responses to the survey.

Of the students surveyed, eighty-two percent said that they would want more learning tools like the Texas Interactive Power Simulator. When asked what they learned while using the simulator via the website, the list was diverse and frequently expressed surprise as key facts such as the current amount of wind generation in the state of Texas, the fuel classifications (renewable vs. non-renewable) for the fuel types, and the variation in water use between different fuels.

# Chapter 5: Scenario Analysis Using the Texas Interactive Power Simulator, Including Energy Efficiency

## 5.1. Overview

The following sections discuss a tradeoff analysis using the methodologies outlined in chapters 3 and 4 for the state of Texas. Four scenarios are presented to illustrate the abilities of the Texas Interactive Power Simulator framework (3 scenarios) and the energy efficiency methodology (1 scenario).

## 5.2. Inputs

Since these scenarios utilize fuel types, instead of indicating specific generation technologies to deploy, input data by fuel were used, incorporating Texas-specific information whenever it was available. These data are shown below in Table 8:

Table 8: Input data by fuel type (8)(38)(40-42)(44-45)

| | **Coal** | **Natural Gas** | **Nuclear** | **Wind** | **Hydro** | **Solar** |
|---|---|---|---|---|---|---|
| **Cost of Capacity (million$/MW)** | 1.5 | 0.9 | 5.0 | 2.5 | 1.7 | 5.0 |
| **Operation &Maintenance Cost ($/MWh)** | 5 | 5 | 15 | 10 | 10 | 9.5 |
| **Fuel Cost ($/MWh)** | 15 | 80 | 5 | 0 | 0 | 0 |
| **$CO_2$ Emissions (lbs/MWh)** | 2293 | 1146 | 0 | 0 | 0 | 0 |
| **$SO_2$ Emissions (lbs/MWh)** | 6.8 | 1 | 0 | 0 | 0 | 0 |
| **$NO_x$ Emissions (lbs/MWh)** | 5 | 0.03 | 0 | 0 | 0 | 0 |
| **Water Consumption (gal/MWh)** | 426 | 223 | 600 | 0 | 0 | 0 |
| **Land Use (acres/MW)** | 1.2 | 0.05 | 0.05 | 25 | 131 | 4.6 |
| **Capacity Factor** | 84 | 80 | 90 | 26 | 22 | 25 |

The first three scenarios presented in this thesis also used the following parameters:

1. End user demand and resulting generation growth rate of 1% per year, yielding a year 2030 total demand of 494 TWh
2. 10% discount rate
3. 3% loan interest rate for construction loan

When using the online interface for the Texas Interactive Power Simulator, these data are available to the user via a series of fuel technology data sheets attached to the main tool interface.

## 5.3. TRADEOFF ANALYSIS WITH THREE SCENARIOS

Three scenarios were analyzed using the Texas Interactive Power Simulator. The generation mix for each scenario is shown below in Table 9.

Table 9: 2030 Generation Mix for Three Scenarios vs. Current Generation Mix(7)

| | Coal | Natural Gas | Nuclear | Wind | Hydro | Solar |
|---|---|---|---|---|---|---|
| **Carbon Price** | 36% | 49% | 10% | 4% | 1% | 0% |
| **Nuclear Renaissance** | 16% | 29% | 50% | 4% | 1% | 0% |
| **High Wind Growth** | 20% | 49% | 10% | 20% | 1% | 0% |
| **Current (2009*)** | 36% | 49% | 10% | 4% | 1% | 0% |
| | 144 TWh | 197 TWh | 40 TWh | 16 TWh | 4 TWh | 0 TWh |

The Carbon Price Scenario (carbon price) examined the effects of putting a price on carbon, a likely result of current energy policy proposals. For the purpose of this analysis, the generation mix was held constant with current day. The purpose of this scenario was to discover and illustrate the effect of a carbon price on the levelized cost of electricity for coal and natural gas electricity generation. Accordingly, no price was assigned to either sulfur dioxide or nitrogen oxides. An initial price of $50 per 2000 pounds ($55 per metric ton) of carbon dioxide was analyzed. This value was chosen to represent an aggressive carbon price scheme. The user's generation mix inputs were not changed due to the carbon price, though it has significant impact on the LCOE for these two generation sources. In practice, this change in cost would undoubtedly affect the generation mix. However, TIPS design is targeted toward allowing the user to designate the generation mix, regardless of the economic and environmental impacts. Clean coal technology is not included in this analysis.

The Nuclear Renaissance Scenario examined a future nuclear renaissance. In this scenario, the percent of total generation from nuclear power rose to 50% of total generation. Additional generation from nuclear was assumed to displace coal and natural gas equally. Many factors are currently acting as drivers toward a nuclear renaissance in the United States, including concerns regarding climate change and the United States' dependence on foreign fuels. This scenario analysis was conducted to understand the economic costs and environmental impacts of a transition from the current fossil fuel based Texas electricity generation mix.

High Wind Growth Scenario analyzed a trend of continued wind market growth in Texas between now and 2030. At the end of 2007, Texas had installed 4,296 MW of wind generation capacity, or approximately ¼ of the entire US wind generation capacity at 16,596 MW. Extensive projects, both on- and offshore are currently either in the planning stage or already under construction. With the extension of the production tax credit for wind energy in the Emergency Economic Stabilization Act of 2008, the trend of continued wind capacity growth is likely to continue. (47)

For Carbon Price Scenario, to achieve the indicated generation mix, $18 billion of new capacity cost was incurred over the 21-year period. This new capacity cost resulted from the need for additional coal, nuclear, and wind power generation facilities to meet growing demand. The final cost LCOE of electricity generation, were as follows:

Table 10: LCOE with carbon tax rises sharply for carbon-intensive fuels

| | **Coal** | **Natural Gas** |
|---|---|---|
| **LCOE without $CO_2$ Tax ($/MWh)** | 20 | 85 |
| **LCOE with $CO_2$ Tax of $55/ton ($/MWh)** | 77 | 114 |
| **Difference in cost ($/MWh)** | **+57** | **+29** |

Table 10 illustrates how dramatically a carbon tax affects the price electricity generated using carbon intensive fuels. With a $55 per ton tax on carbon dioxide emissions, the cost gap between coal and natural gas generation drops over 40 percent from $65 per MWh to $37 per MWh. Coal, with its higher rate of carbon dioxide emissions during generation is affected more intensely than natural gas by a carbon tax policy. Because the generation mix itself has not changed in this analysis, the environmental impacts were identical per MWh in both the current and the future mix.

In Nuclear Renaissance scenario, the amount of generation from nuclear power was increased to 50% of total generation. To meet the generation mix requirements for this scenario, TIPS found that a capital investment of $118 billion would be required for new nuclear power plant construction. Nuclear power would have a resulting levelized cost of electricity (LCOE) of $86.

The increase in the percent of total generation that comes from nuclear power had a noticeable impact on the environmental impacts that were calculated using the Texas Interactive Power Simulator. These impacts are quantitatively displayed below in Table 11.

Table 11: Air emissions are reduced and water consumption is increased with higher nuclear power use

| | Air Emissions ($10^9$×lbs/year) | | | Water Consumption ($10^9$×gal/year) |
|---|---|---|---|---|
| | **$CO_2$** | **$SO_2$** | **NOx** | |
| **Current Generation mix** | 690 | 1.5 | 0.9 | 160 |
| **Nuclear Renaissance Scenario** | 350 | 0.7 | 0.4 | 210 |
| **% Change** | **-49%** | **-55%** | **-56%** | **+31%** |

Total annual air emissions were reduced by 49%, 55%, and 56% for carbon dioxide, sulfur dioxide, and nitrogen oxides respectively. Waster consumption increased by 31% from $1.6 \times 10^{11}$ to $2.1 \times 10^{11}$ gallons consumed per year. This increase in water consumption leads to potential concerns for water-constrained states.

In High Wind Growth Scenario, the increase in electricity generation from wind resulted in a new capacity cost of $71 billion and a LCOE for wind of $124 per MWh. While some of this capacity cost ($3 billion) was due to increasing nuclear capacity with the increasing electricity demand, the majority of this cost ($68 billion) was associated with the new wind generation capacity required to supply the more than 48 TWh that will be needed from wind generation in 2030 with a 1% per year demand growth rate. All construction is front-loaded (e.g., wind turbines are assumed to be installed as quickly as allowed given construction timeline constraints shown in Table 12). In this scenario, concerns regarding wind intermittency and its effects on system reliability are negated by an excess of natural gas generation capacity.

Environmental impacts were also affected with this increase in wind power generation. Air emissions, again weighted per MWh of generated electricity decreased significantly with increasing wind power generation.

Table 12: Environmental impacts decrease as wind generation increases

| | Air Emissions ($10^9$ lbs/year) | | | Water Consumption ($10^9$ gal/year) |
|---|---|---|---|---|
| | $CO_2$ | $SO_2$ | NOx | |
| **Current Generation mix** | 690 | 1.5 | 0.9 | 160 |
| **High Wind Growth Scenario** | 504 | 0.9 | 0.5 | 126 |
| **% Change** | **-27%** | **-40%** | **-44%** | **-21%** |

### 5.4. MAXIMIZING ENERGY EFFICIENCY

The fourth and final scenario presented is one in which the user assumed that the total electricity demand in 2030 is higher than current demand, as calculated using an annual growth rate of 2.1%, for reasons discussed in the following sections. The user then chooses to meet the state's 2030 electricity demand by first maximizing energy efficiency, and then satisfying the remaining generation requirements through a combination of nuclear and renewable generation technologies, as outlined in the following sections. As we will see in the following sections, the electricity demand increases for our scenario will largely be met using energy efficiency. However, due to concerns over the emission of greenhouse gases by power plants, the user will choose to shift the current electricity mix in Texas to one more heavily dependent on wind and nuclear power. These changes will result in a 2020 generation mix that includes 20% of its generation from nuclear power and 7% from wind power, reducing coal power's production to just 23% of the electricity generation mix.

This scenario not only illustrates the importance of determining realistic maximum energy efficiency limits, but also shows the non-obvious tradeoffs between fuel choices. In this case, the non-obvious tradeoff exists with the nuclear power generation, which reduced the carbon intensity of the electricity mix in terms of pounds of carbon dioxide emitted per kilowatt-hour (kWh) of electricity generated, but actually increases the water intensity (gallons of water consumed per kWh) of the generation mix.

### 5.4.1 DETERMINING FUTURE NET SALES FOR TEXAS

In 2007, Texas's annual net sales of electricity for all sectors totaled approximately 344 TWh ($NS_{2007}$). (22) This value was applied to Equation X to determine the net sales in 2020 ($NS_{2020}$). The Energy Information Administration's 2010 Annual Energy Outlook projected an average annual increase in net sales of electricity (MWh/year) in the United States of 0.8% per year from 2007-2020. (48) This growth rate was applied to Equation 23 (below) for a period of 13 years (n). This calculation yielded a net sale ($NS_{2020}$) of just over 381 terawatt-hours (TWh) in 2020.

$$NS_{2020} = (NS_{2007}) \times (Growt \quad Rate)^{n}$$

Eq. 23

However, this value is almost certainly an underestimate when other factors are included. Most significantly, the United States Census Bureau's projected population growth rate for Texas predicts a population increase in the state of over 4 million people by 2020. Using this projected population increase Texas would have to reduce its current annual per capita electricity use of 14.4 MWh by approximately 1 MWh (7%) in order to meet the EIA projections as shown in Table 1. (34)

The Electric Reliability Council of Texas (ERCOT) predicts a more aggressive rate of growth for Texas net sales of 2.1% per year over all sectors. ERCOT's service region includes approximately 85% of all electricity used in Texas and it was assumed that their anticipated sales growth rate could reasonably be extended to the remaining 15%. (49) This assumption is consistent with historic trends in Texas of electricity sales growth in the ERCOT region versus the entire state as seen in the Energy Information Administration's state profiles historic data. (50) This calculation yielded 2020 net sales of just over 450 TWh for the state. Using the previously discussed expected 2020 Texas population of 28.6 million people, this net sales value corresponds to a per capita electricity use of 15.7 megawatt-hours per year.

Notable here is that while ERCOT projections predict a per capita electricity use in the state of Texas of 15.7 megawatt-hours per person, the trend in the state over the last decade shows a stabilization at under 15 megawatt-hours per capita per year as shown in the following section in Figure 1. It is reasonably concluded that the ERCOT growth rate yields a more likely future scenario than the EIA U.S. average growth rate produces, as the latter would require a significant decrease in per capita electricity sales in Texas. For this scenario analysis, I predicted the electricity net sale using the ERCOT growth rate.

### 5.4.2 MAXIMIZING ENERGY EFFICIENCY

As discussed in Chapter 3, Texas might be able to realize an annual per capita electricity savings of 2.7% to 11% due to energy efficiency. For the purpose of this scenario, we will take the largest efficiency in this range, or 11% (1,587 kWh per capita per year). By applying this efficiency gain to the per capita electricity demand of 15.7 MWh, we reduce our annual per capita electricity demand to 14.1 MWh. The U.S. Census Bureau's prediction that Texas's population in 2020 will have reached approximately 28.6 million people. (34) Therefore, with a 14.1 MWh annual per capita electricity demand, the total demand for the state of Texas in 2020 is projected to be 403 terawatt-hours (TWh). This is actually quite close to the 2008 total generation in the state of 401 TWh. (50) This is significant because, without factoring in power plant requirements, this analysis indicates that Texas might avoid a need to build new power plants for the next decade if it chooses to implement aggressive energy efficiency measures.

### 5.4.3 CHANGING THE TEXAS ELECTRICITY MIX

As indicated earlier in this chapter, this scenario includes the shift toward increased use of nuclear and wind power to satisfy electricity demand. By shifting electricity generation to 20% nuclear power and 7% wind power, and reducing coal to just 23% of the total electricity mix we see and overall increase in average operation and maintenance cost from $6 to $7 per MWh, and a decrease in average fuel cost from $45 to $44 per MWh. We also see that new construction requirements for nuclear and wind capacity will cost a total of $39 billion (overnight costs). These results are shown below in Figure 15.

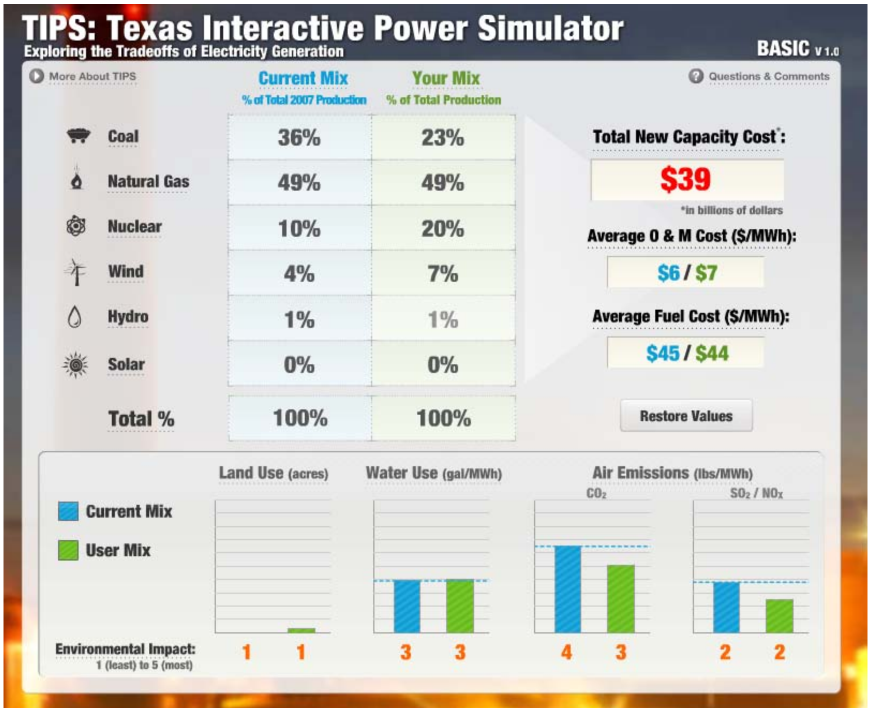



Figure 15: TIPS output for scenario analysis including increased use of nuclear and wind power generation

In terms of environmental tradeoffs, these changes significantly decreased the average air emissions (lbs/MWh) for all three greenhouse gases. But, the average water use increased due to the increased use of nuclear power in our generation mix. Further, total land use (in acres) increased with the increase in wind power due to the land use intensity of wind.

# Chapter 6: Summary of Conclusions and Recommendations

This research project addressed the need for a readily accessible, quantitative methodology for establishing the economic and environmental tradeoffs of electricity generation technologies in the United States. It did this by establishing a methodology for calculating not only the tradeoffs in different electricity generation technologies, but also by establishing a methodology for determining appropriate maximum levels of energy efficiency for individual states (or regions).

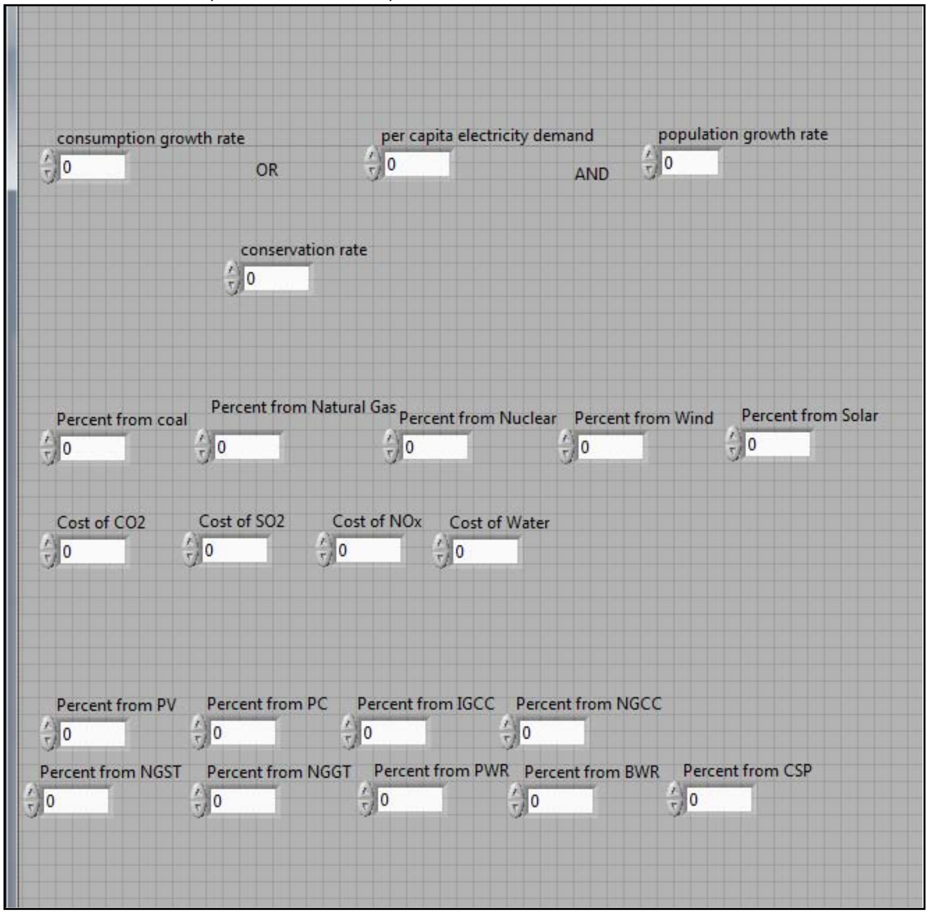
The methodology for determining energy efficiency limits was based on previous analysis of the Rosenfeld Effect as conducted by researchers at Stanford University. This methodology was broken down by sector (residential, industrial, and commercial) and category (for example, heating load reductions and possible policy impacts). Applying this methodology to the state of Texas produced a possibly optimistic upper bound for potential energy efficiency "savings" of 11% of per capita electricity use. This maximum "savings" value is high compared to published values by the Public Utility Commission of Texas (2.7% to 4.5%) and the American Council for an Energy Efficient Economy (up to 9.6%). This high value might indicate that Texas has already achieved a certain amount of energy efficiency. Alternatively, it could indicate that particular characteristics inherent to California (for example, climate) are significant drivers behind the stabilized per capita electricity use seen in the state. In this case, it might be difficult to reproduce the Rosenfeld Effect in other states using the same "savings" categories as was identified for contributing to the per capita electricity sales stabilization observed in California.

After applying this methodology to the state of Texas, and seeing its seemingly high projected potential energy efficiency "savings" output, future research opportunities became apparent. These opportunities include the collection and utilization of a common data source that provides data for at least all of the states in the U.S., if greater granularity is not available. It could also be interesting to evaluate the level of energy efficiency that has already been achieved in other states in order to better estimate potential future energy “savings” from energy efficiency. The methodology developed in this research for analyzing the tradeoffs of changes to the electricity generation mix was applied specifically to Texas to develop the Texas Interactive Power Simulator (TIPS), an interactive online tool accessible via the internet. This tool has been used in classrooms at The University of Texas at Austin, for both undergraduate and graduate courses where is has received praise for its ability to communicate information regarding economic and environmental tradeoffs to a wide audience. According to preliminary data collected from the students via surveys, this tool is useful as a classroom aid and self-teaching environment.

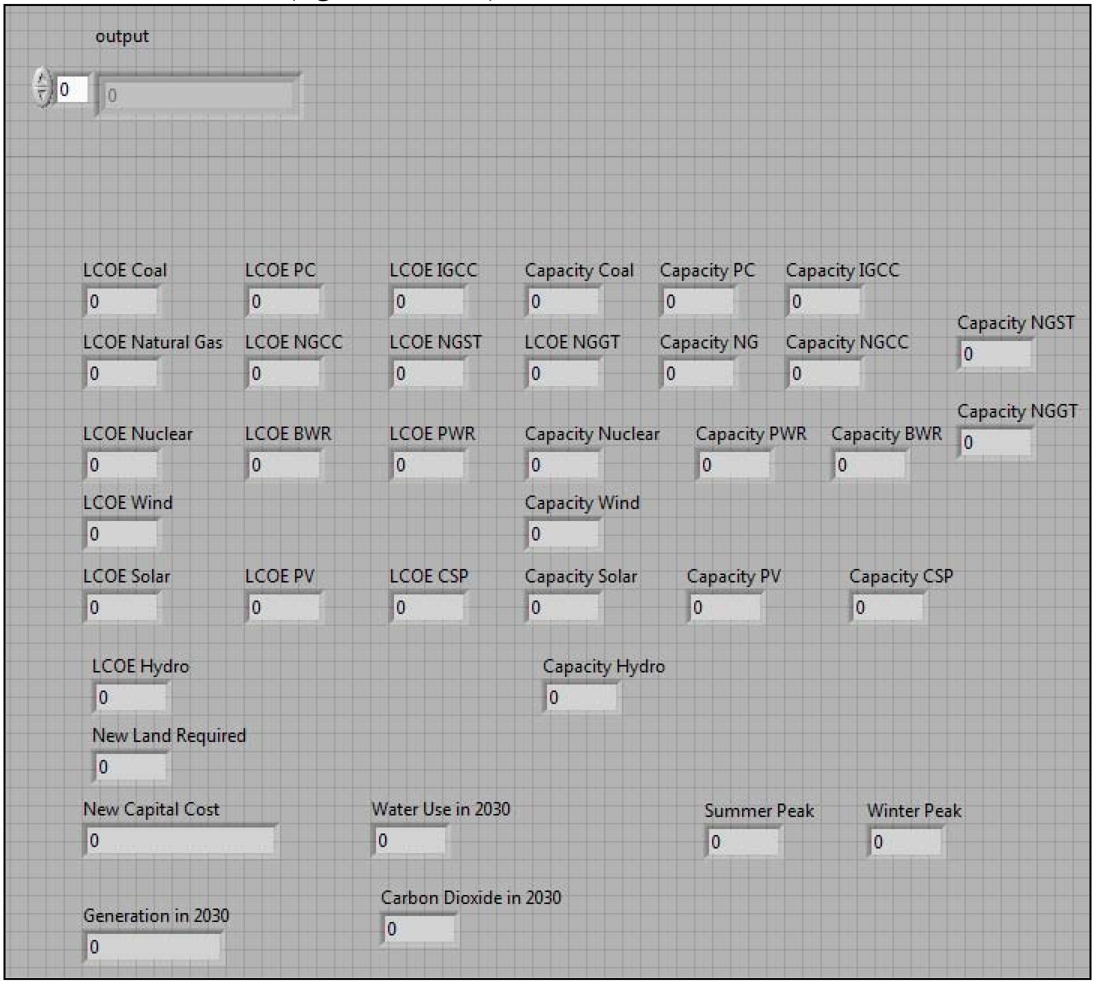
# Appendix A: Texas Interactive Power Simulator LabVIEW Code

## A.1. TIPS ADVANCED WITH SUB-VIS – MAIN INTERFACE

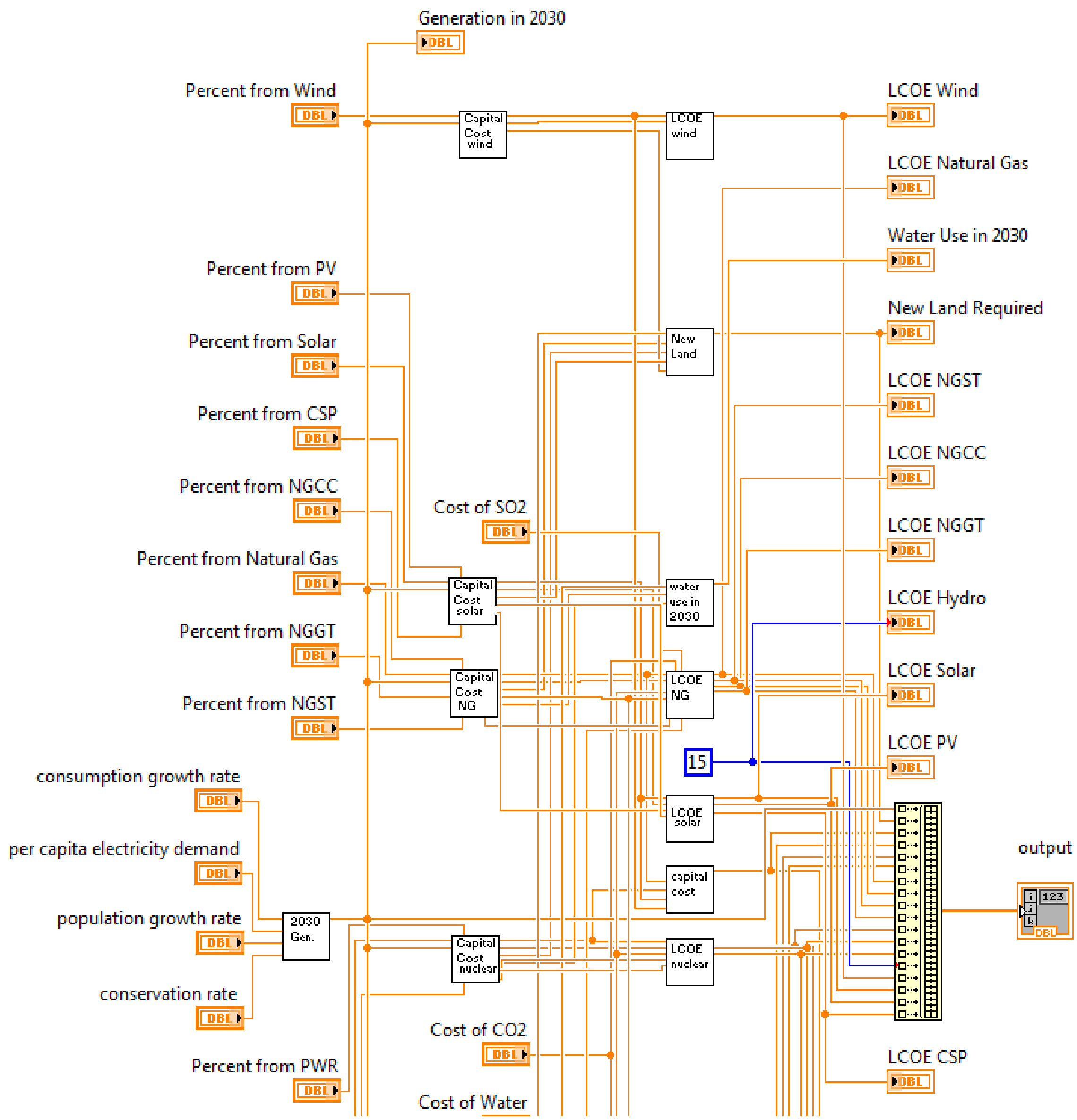
Frontend User Interface (left-hand side)



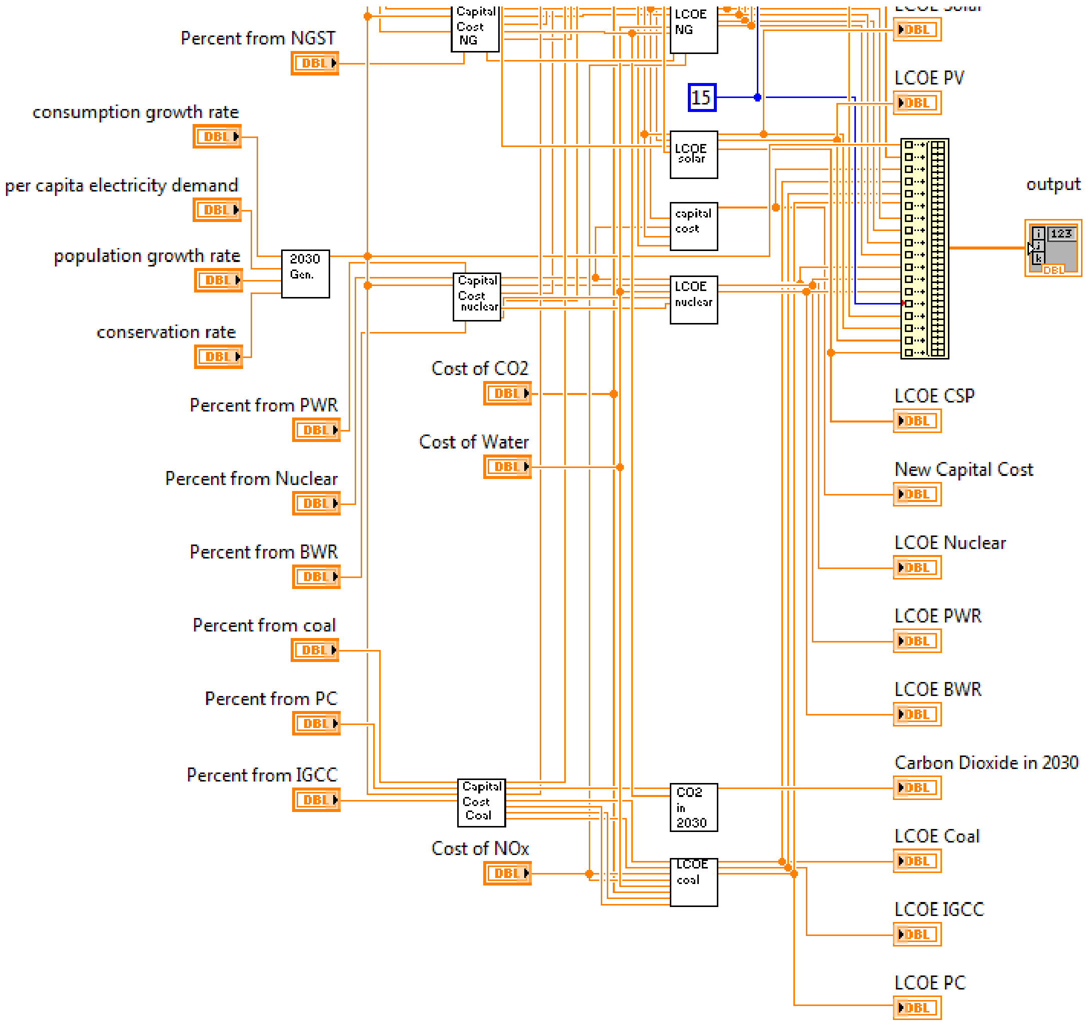
Frontend User Interface (right-hand side)



Block Diagram – Part 1 (top portion)

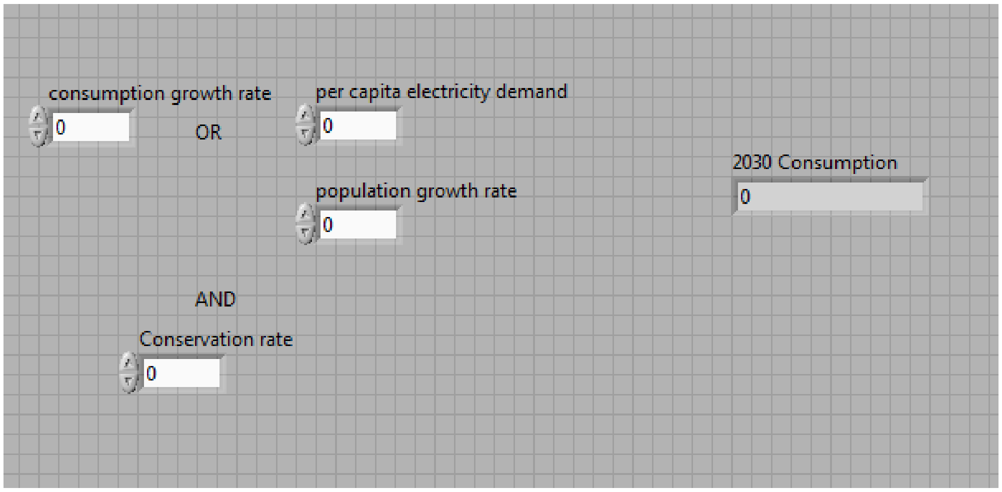


Block Diagram – Part 2 (bottom portion)

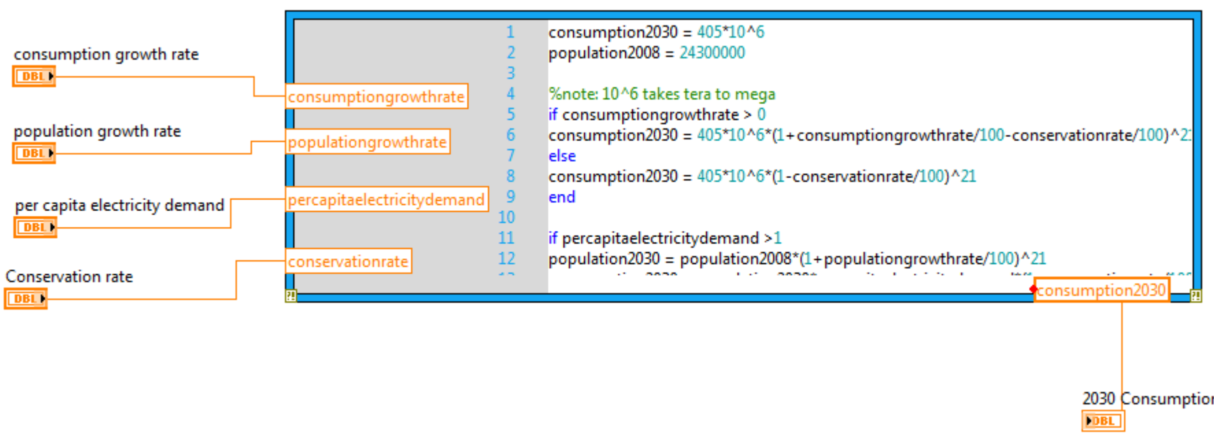


## A.2. Sub-VI #1 – Total Generation

Frontend User Interface

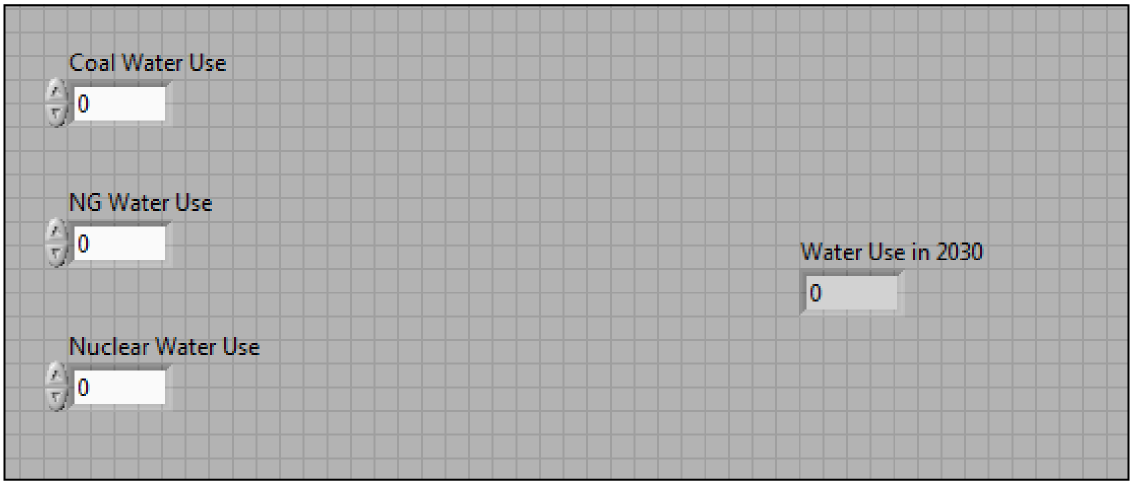



Block Diagram



### A.3. SUB-VI #2 – WATER USE

Frontend User Interface

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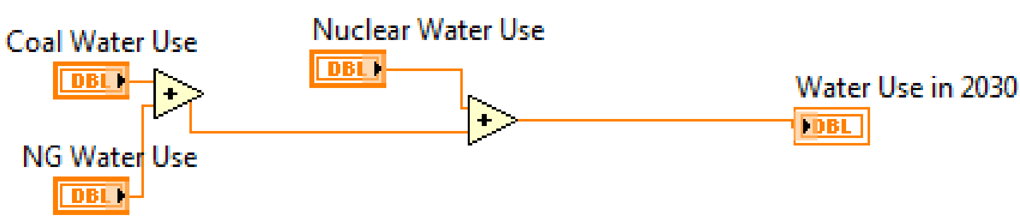
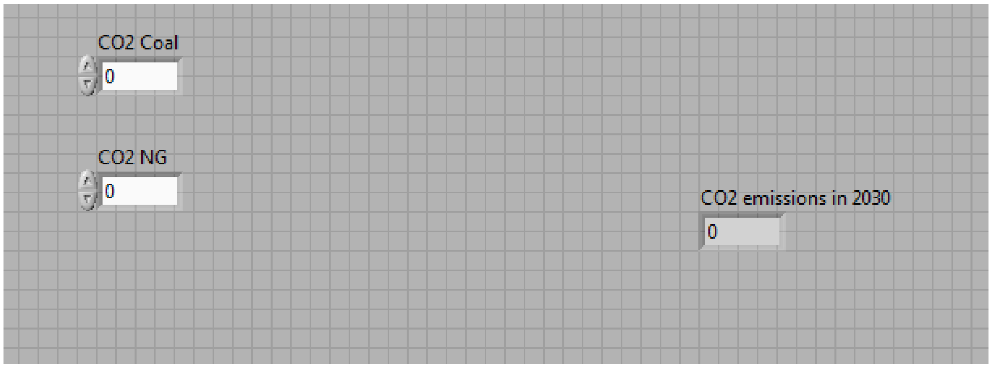


### A.4. SUB-VI #3 – $CO_2$ EMISSIONS

Frontend User Interface

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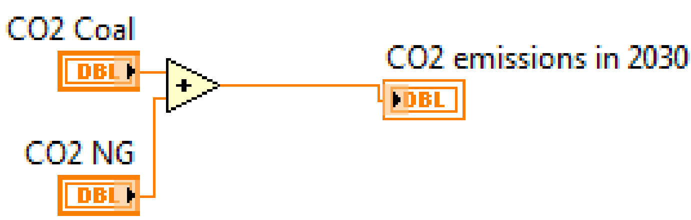
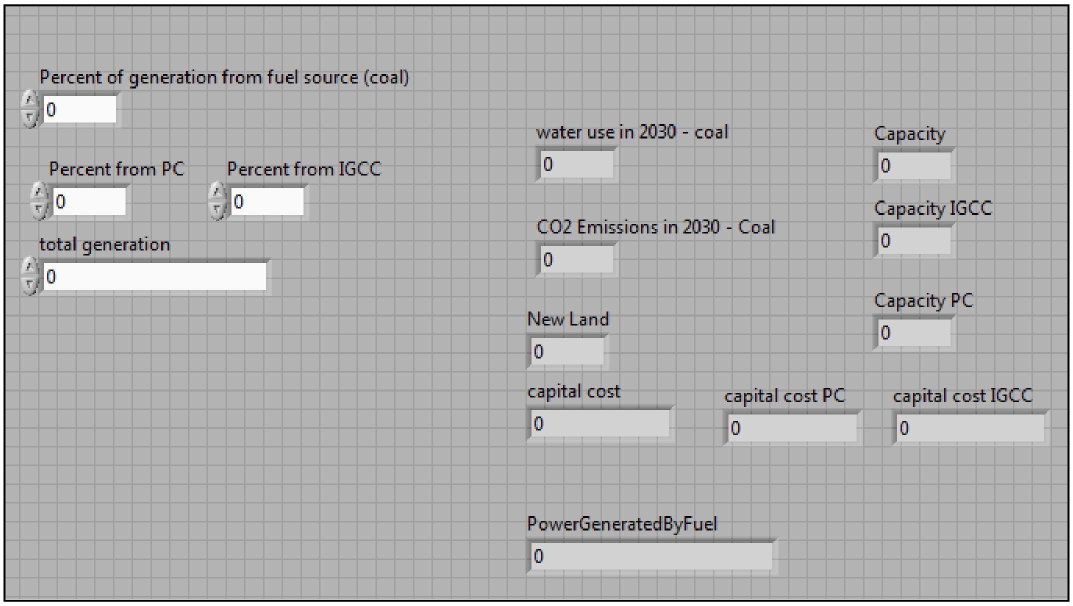


## A.5. Sub-VI #4 – Capital Cost Coal

Frontend User Interface

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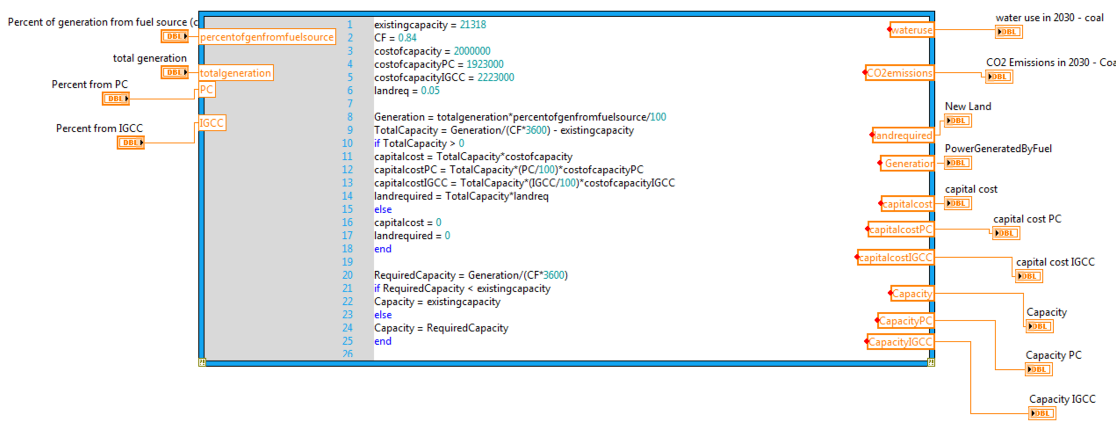
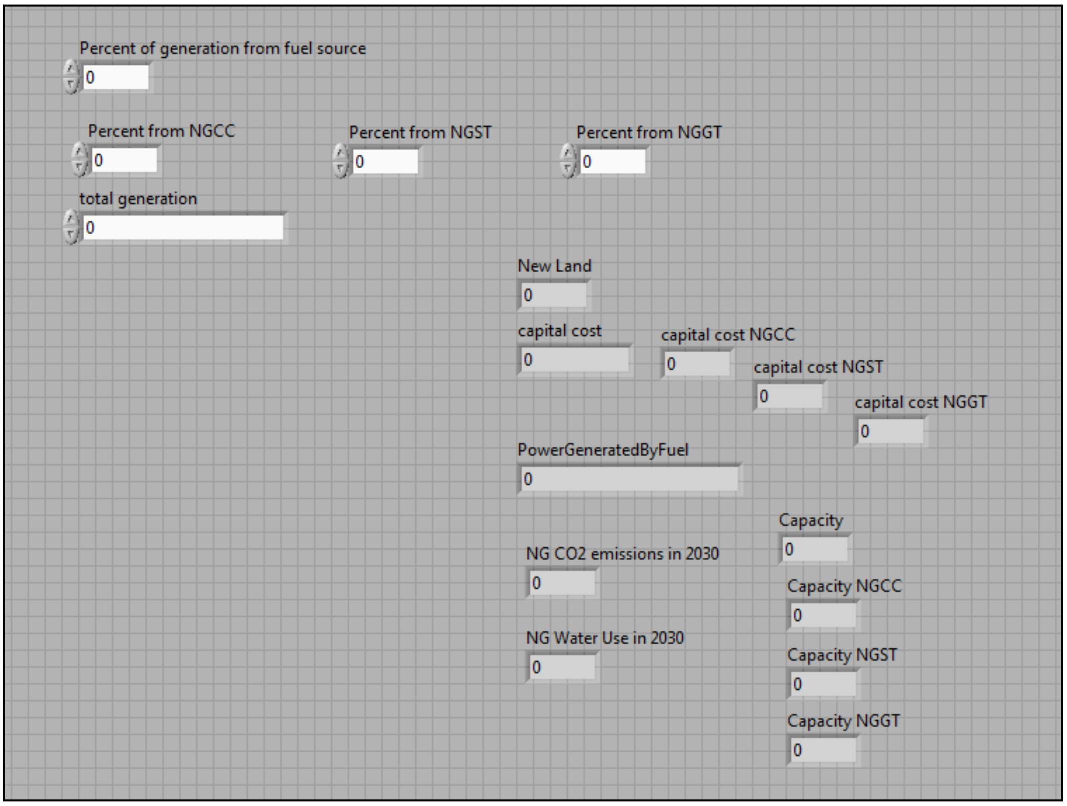


## A.6. Sub-VI #5 – Capital Cost Natural Gas

Frontend User Interface

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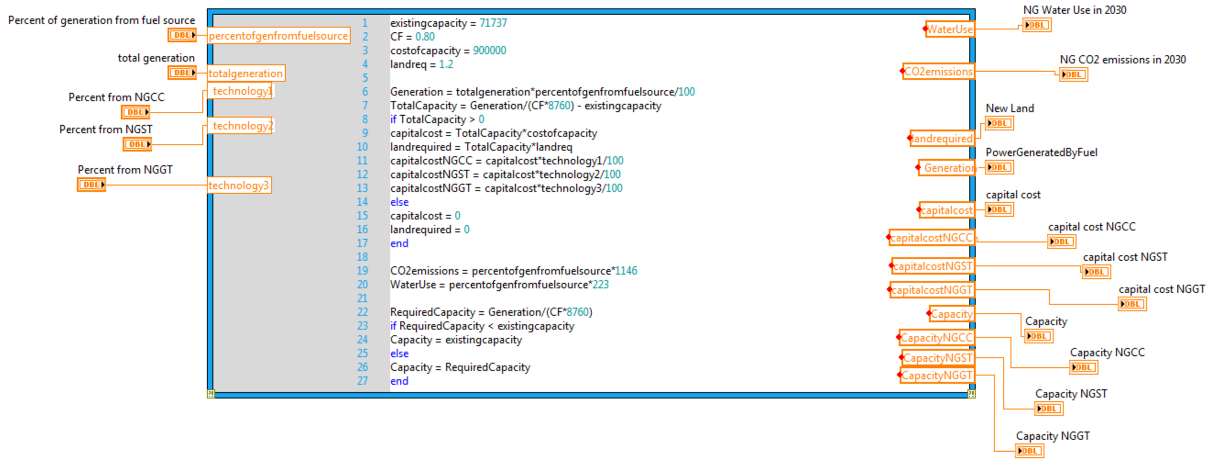
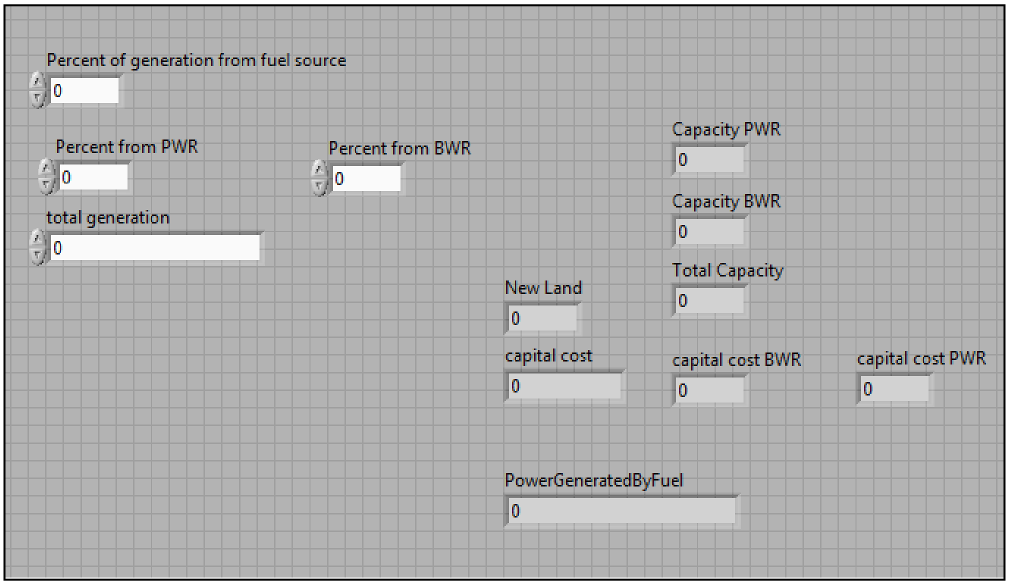
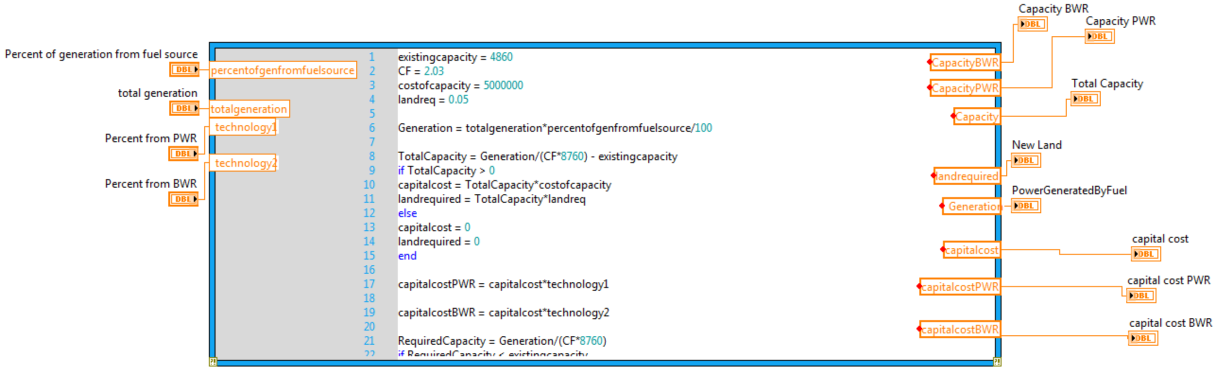


## A.7. SUB-VI #6 – CAPITAL COST NUCLEAR

Frontend User Interface

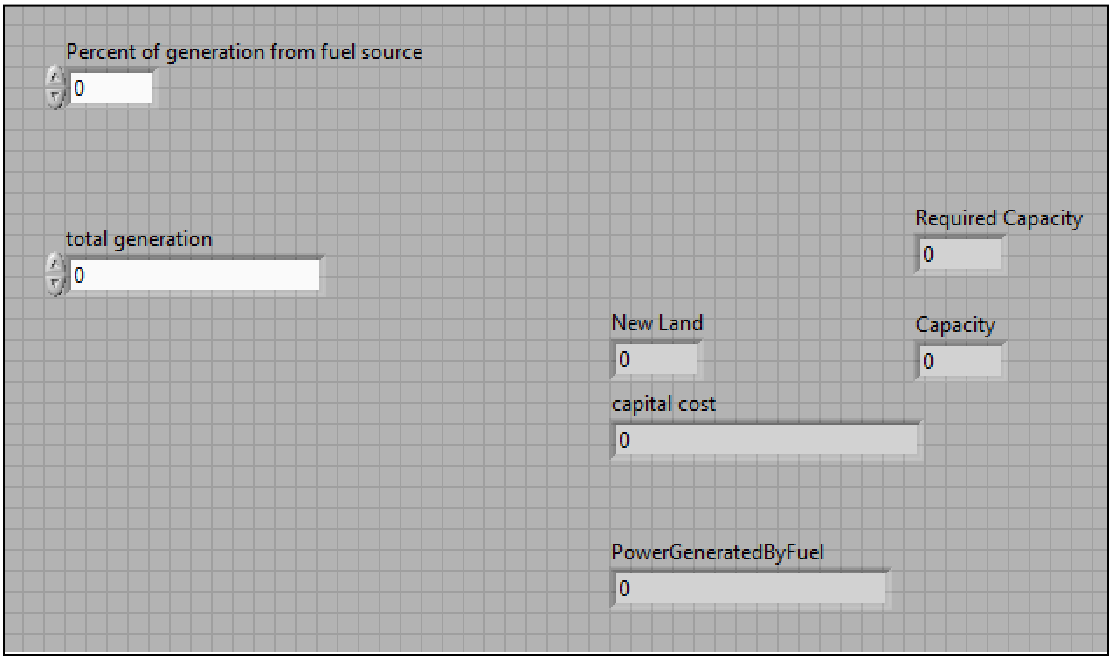



Block Diagram

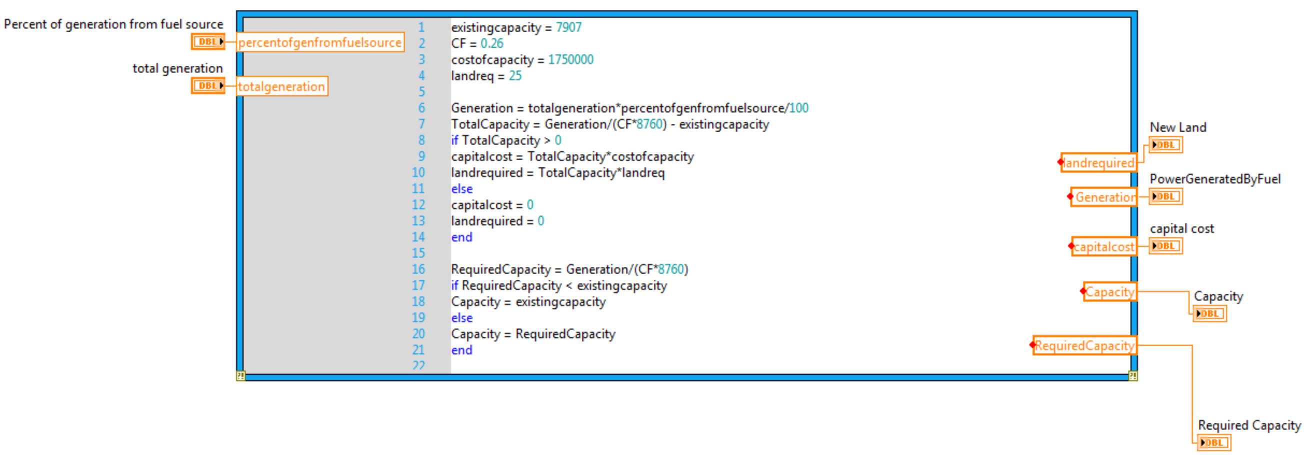


## A.8. Sub-VI #6 – Capital Cost Wind

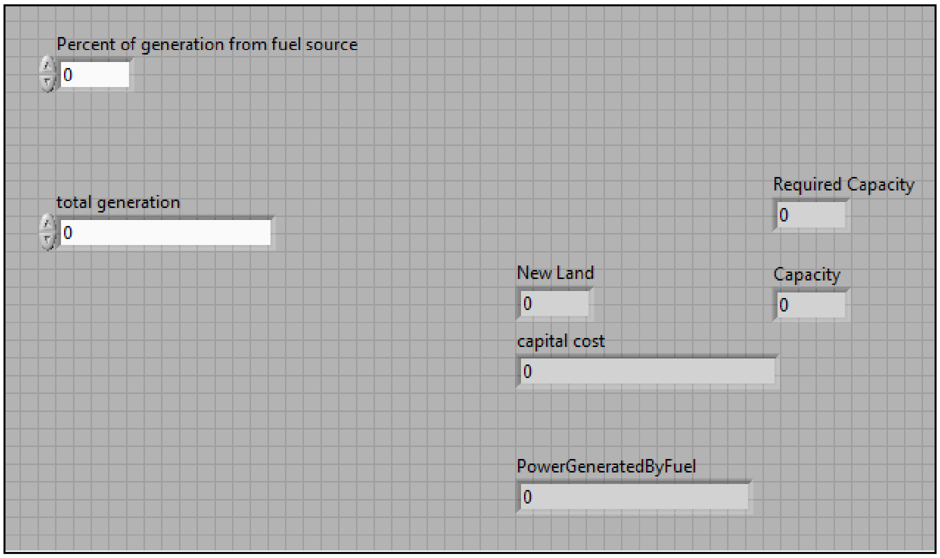
Frontend User Interface

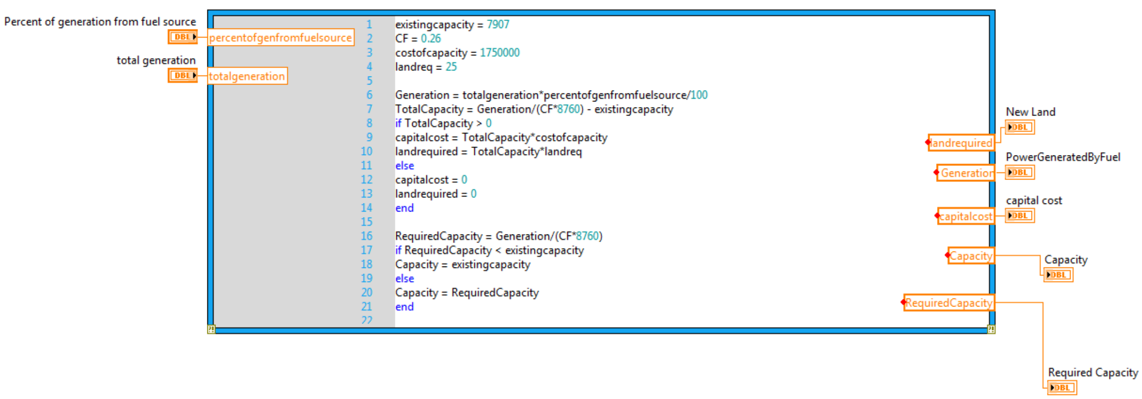



Block Diagram



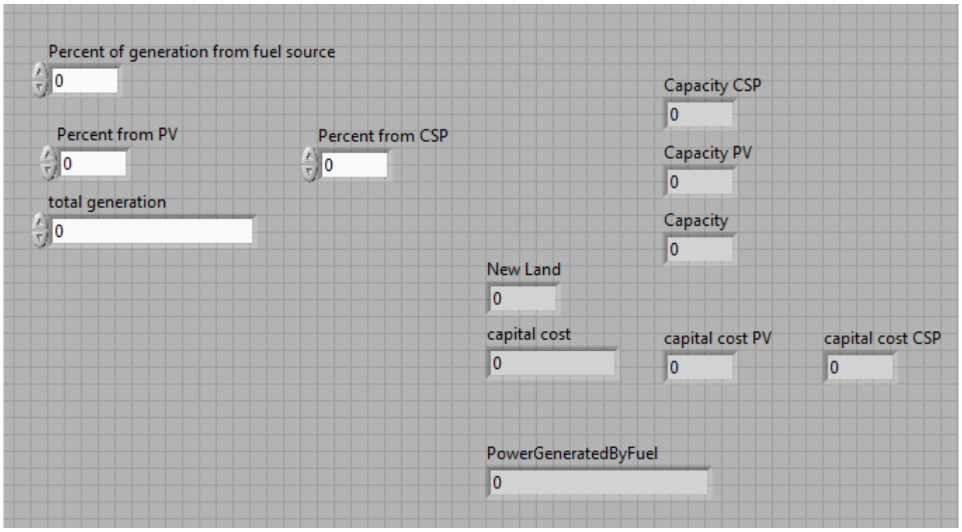
## A.9. SUB-VI #6 – CAPITAL COST HYDRO



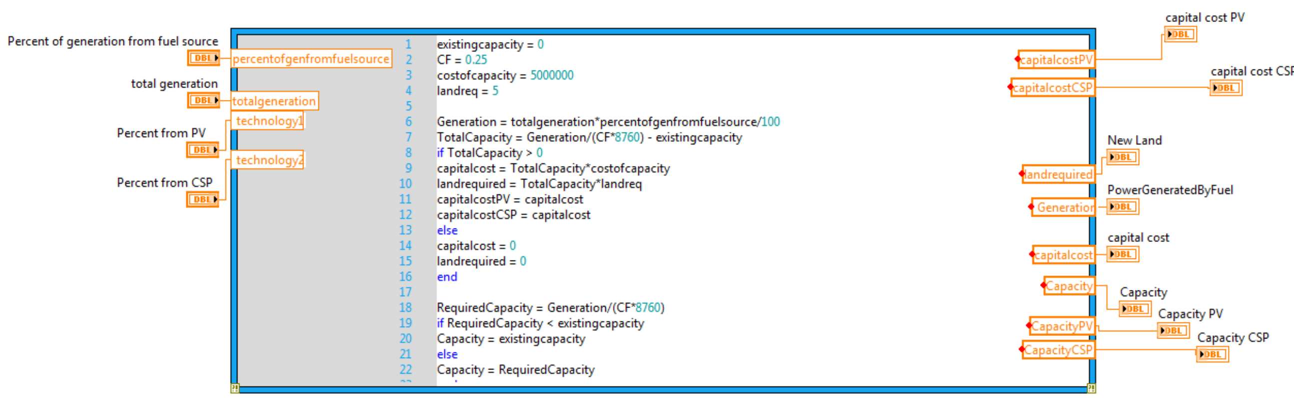



## A.10. Sub-VI #6 – Capital Cost Solar

Frontend User Interface




Block Diagram



# Appendix B: Texas Interactive Power Simulator - Course Surveys

## B.1. Pre-Survey Homework Assignment

**Texas Interactive Power Simulator (TIPS) Assignment**
http://ficp.engr.utexas.edu/tips
**Due1/30/2009, at beginning of discussion section**

**Name:** ________________________________
**Date:** ________________________________
**Section:** ______________________________
**Hometown:** ____________________________

For questions 1-4 & 7b, please select from the following choices:

1. Coal — 4. Wind
2. Natural Gas — 5. Hydroelectric (water)
3. Nuclear — 6. Solar (sun)

**Question 1**: In the state of Texas, the majority of electricity is currently produced using ________________.

**Question 2:** When used for electricity generation in Texas, power from ______________ emits the most carbon dioxide ($CO_2$) into the air per unit of electricity generated.

**Question 3:** When used for electricity generation in Texas, power from __________________ consumes the most water per unit of electricity generated (most gallons/unit electricity generated).

**Question 4:** In terms of electricity generation (power plants) in the state of Texas, power from ______________ is the most land intensive (uses the most land per power plant unit).

**Question 5:** What percentage of total electricity generation in Texas is currently supplied by nuclear power?

____________ %

**Question 6:** In the state of Texas, how much electricity was generated in 2007?

1. 41 terawatt-hours (TWh)
2. 41 terawatts (TW)
3. 1,000,000 terawatts (TW)
4. 401 terawatt-hours (TWh)
5. 401 terawatts (TW)

**Question 7**

a. Define cost of capacity.

b. Generation technology which uses ______________ as its fuel has the highest cost of capacity.

## B.2. Post-Survey

**Texas Interactive Power Simulator (TIPS) Assignment #2**

http://ficp.engr.utexas.edu/tips

**To be completed in discussion section**

**GRADE**: Your grade on this assignment will not be determined by your answers to the questions. You will receive full credit for the assignment by completing all of the questions

**Name:** ________________________________

**Date:** ________________________________

**Section:** ________________________________

**Question 1**: Did you have any problem accessing the site?

a. No
b. Yes (explain)

**Question 3**: How long did you spend using the website?

a. 0 – 10 minutes
b. 11 – 20 minutes
c. 20 – 30 minutes
d. > 30 minutes

**Question 4**: Do you believe that the website is credible?

a. No (explain)

b. Yes (explain)

**Question 5**: Was the website a valuable learning tool?

a. Yes
b. No

**Question 6**: Do you believe that the website was useful in illustrating the environmental and economic tradeoffs of electricity generation methods in Texas?

a. Yes
b. No

**Question 7**: Did you like using the website?

a. Yes
b. No

**Question 8**: Would you like to have more learning tools like this?

a. Yes
b. No

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### B.3. 2009 Post-Survey Results and Raw Data

**Question 1**: Did you have any problem accessing the site?

a. No - 63
b. Yes – 6
c. No response - 1

**Question 2:** How long did you spend using the website?

a. 0 – 10 minutes - 3
b. 11 – 20 minutes - 28
c. 20 – 30 minutes - 33
d. > 30 minutes – 5
e. No response - 1

**Question 3:** Do you believe that the website is credible?

a. No - 3
b. Yes - 63
c. No response - 4

**Question 4:** Was the website a valuable learning tool?

a. Yes - 64
b. No – 5
c. No response – 1

**Question 5:** Do you believe that the website was useful in illustrating the environmental and economic tradeoffs of electricity generation methods in Texas?

a. Yes - 65
b. No – 4
c. No response - 1

**Question 6:** Did you like using the website?

a. Yes – 52.5*
b. No – 16.5*
c. No response – 1

*1 responder indicated both answers "yes" and "no" for this question

**Question 7:** Would you like to have more learning tools like this?

a. Yes - 56
b. No – 12
c. No response – 2

**Total Number of Surveys Completed: 70**

| | Question 1 | | Question 2 | | | | Question 3 | | Question 4 | | Question 5 | | Question 6 | | Question 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Yes*** | ***No*** | ***0 to 10*** | ***11 to 20*** | ***20 to 30*** | ***> 30*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** |
| 1 | | 1 | | | | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| 2 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 3 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 4 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 5 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 6 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 7 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 8 | | 1 | | | 1 | | 1 | | | 1 | 1 | | 1 | | 1 | |
| 9 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 10 | 1 | | | | | 1 | 1 | | 1 | | | 1 | | 1 | 1 | |
| 11 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 12 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 13 | 1 | | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 14 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 15 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 16 | | 1 | | | 1 | | 1 | | 1 | | | 1 | 1 | | 1 | |
| 17 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 18 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 19 | | 1 | | | | 1 | 1 | | 1 | | 0.5 | 0.5 | 1 | | 1 | |
| 20 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 21 | | 1 | | 1 | | | 1 | | 1 | | 1 | | | 1 | 1 | |
| 22 | | 1 | | | | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| 23 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 24 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 25 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 26 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 27 | | 1 | | | | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| 28 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 29 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 30 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 31 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 32 | | 1 | 1 | | | | 1 | | | 1 | | 1 | | 1 | | 1 |

| | Question 1 | | Question 2 | | | | Question 3 | | Question 4 | | Question 5 | | Question 6 | | Question 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Yes*** | ***No*** | ***0 to 10*** | ***11 to 20*** | ***20 to 30*** | ***> 30*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** |
| 34 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 35 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 36 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 37 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 38 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 39 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 40 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 41 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 42 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 43 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 44 | | 1 | | 1 | | | 1 | | 1 | | | 1 | 1 | | 1 | |
| 45 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 46 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 47 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 48 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 49 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 50 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 51 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 52 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 53 | | 1 | | | | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| 54 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 55 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 56 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 57 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 58 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 59 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 60 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 61 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 62 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 63 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 64 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 65 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |

| | Question 1 | | Question 2 | | | | Question 3 | | Question 4 | | Question 5 | | Question 6 | | Question 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Yes*** | ***No*** | ***0 to 10*** | ***11 to 20*** | ***20 to 30*** | ***> 30*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** | ***Yes*** | ***No*** |
| 66 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 67 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 68 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 69 | | 1 | 1 | | | | | 1 | 1 | | 1 | | | 1 | 1 | |
| 70 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 71 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 72 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 73 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 74 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 75 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 76 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 77 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 78 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 79 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 80 | 1 | | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 81 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 82 | | 1 | 1 | | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 83 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |
| 84 | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | 1 | |

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# Vita

Melissa Christenberry Lott was born on December 7, 1982 to Gus Kaderly Lott, Jr. and Mary Christenberry Lott when her older brother, Gus Kaderly Lott, III, was 3 years old. She graduated from Monterey High School in Monterey, California in 2000 after which she enrolled at the University of California, Davis for undergraduate study. While in school as an undergraduate, Melissa was active in Chi Omega Sorority, where she held several offices including Recruitment Chair and was awarded top awards for academic achievement by the UC Davis Panhellenic Council in 2001, 2001, and 2003. Ms. Lott was active in the UC Davis chapter of the Biomedial Engineering Society (BMES), holding the office of President from 2003-2005.

Ms. Lott spend the summer of 2003 studying renewable energy at The University of Canterbury at Christchurch on New Zealand's south island where she completed research on photovoltaic and other solar technologies. In the winter and summer of 2004, Ms. Lott worked as a cooperative student at Sandia National Laboratories in Albuquerque, New Mexico where she conducted research in microfluidics and micro-electromechanical (MEMS) devices.

Ms. Lott has worked for YarCom Inc. as an engineer and consultant in energy systems and systems design since 2004. She worked for General Mills from 2005-2006 as a systems engineer in their Albuquerque facility. In 2009, Ms. Lott worked for the Department of Energy, Energy Information Administration (EIA) as a student trainee in engineering where she analyzed EIA data collection efforts for renewable energy technologies and power generation water use. In the fall of 2009, she worked for the

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Ms. Lott's work on the tradeoffs of electricity systems, electricity transmission and distribution, and energy in Texas has been published by Discover Magazine, Scientific American, the Austin Post, and the Austin American Statesman.

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